THE PLEISTOCENE GEOLOGY OF NORTHWESTERN IOWA

BY

J. ERNEST CARMAN

CONTENTS

Introduction 239
Chapter I—Earlier Work in Northwestern Iowa................. 241
Work Preceding the Organization of the Present Iowa Geological Survey 242
Work Since the Organization of the Present Iowa Geological Survey 244
Chapter II—The Wisconsin Drift-Region........................ 251
General Characteristics 251
Topography 251
Drift 252
The West Boundary.. 252
Earlier Work on the Wisconsin Boundary.......... 252
Criteria for Distinguishing the Wisconsin Boundary. 254
Retracing the Wisconsin Boundary................. 255
South of Sac County.................................... 255
From the South Line of Sac County to the Little Sioux Valley at the Mouth of Brooke Creek 256
Along the Little Sioux Valley from Brooke Creek to Gillett Grove....................... 260
From Gillett Grove to the Dickens Outlet..... 266
The Ruthven Moraine.......................... 270
From the Dickens Outlet to the Okoboji Outlet 272
The Terminal Moraine Around Okoboji Lakes. 275
From the Okoboji Outlet to the Ocheyedan River 278
From the Ocheyedan River to the State Line. 282
The Wisconsin Drift-Region in Northeastern Osceola County 285
The Boundary North of the State Line........ 287
Summary 290
Comparison of the Course as Retraced with Earlier Tracings 292
The Wisconsin Drift in the Region of Sioux Falls....... 294
Earlier Work 294
Characters of the Wisconsin Drift-Plain............ 297
The Wisconsin Drift-Boundary near Sioux Falls... 301
The Drift 302
Absence of Loess.................................... 304
Summary 305
Drainage Changes Caused by the Wisconsin Ice.......... 308

Drainage Changes in the Little Sioux River Basin.. 310
Course of the Mississippi-Missouri Divide.... 310
Altitude of the Mississippi-Missouri Divide... 310
Pattern of drainage........................ 312
Conclusions 313
Possible Pre-Wisconsin Stream Courses and the Successive Drainage Changes......... 313
Drainage Changes in the Boyer River Basin....... 318
Conclusions 320
Chapter III—The Kansan Drift-Region....................... 320
Topography 322
General Characteristics 322
Description of the Topography.................... 323
The Slightly Rolling Areas.................. 323
The Rolling Areas.......................... 325
The Rugged Areas.......................... 325
Aggraded Areas 326
Sharply Dissected Areas Along Valleys...... 327
Gravel Hills 330
Gravel Benches 330
Sand Hills North of the Spencer Flat........ 331
History of the Kansan Topography............... 332
The Kansan Drift.. 334
General Characteristics 334
Source of Material for the Drift................. 337
Explanation of the Freshness of the Till.......... 338
The Loess.. 339
General Characteristics and Distribution.......... 339
Topographic Influence of the Loess............... 342
The Loess of the Kansan Region................. 342
Pebbles Within and on the Surface of the Loess.... 343
Data Concerning the Nature and Thickness of the Loess 349
From Wall Lake West Across Southern Sac and Ida Counties........................ 349
From Early West Across Northern Sac and Ida Counties 349
From Storm Lake West Across Buena Vista, Cherokee and Plymouth Counties........ 351
O'Brien and Sioux Counties................. 353
Clay and Dickinson Counties.............. 354
Osceola and Lyon Counties................. 354
Southern Nobles County, Minnesota.......... 356
Origin and Age of the Loess...................... 356
Chapter IV—The Associated Gravels.......................... 357
Gravel and Sand Masses Included in the Till........... 357
General Characteristics 357
Description of Some Typical Gravel Masses........ 359
The Origin of the Sand and Gravel Bowlders...... 361

The Gravel Hills ... 362
Nature of the Gravel ... 362
Distribution and Description of the Gravel Hills ... 363
Northeastern Lyon County ... 363
Southwestern Nobles County, Minnesota ... 364
Western Osceola County ... 364
Northern O'Brien County ... 364
Along Willow Creek in Southern O'Brien County ... 365
Northern Cherokee County ... 367
Southeastern Cherokee County ... 367
Northeastern Ida County ... 369
Sac County ... 369
The Origin of the Gravel Hills ... 370
Evidence of Structure ... 370
Evidence of Location ... 370
Evidence of Material ... 371
Conclusions ... 371
Interbedded Gravel and Till ... 372
Distribution and Description of Exposures ... 372
Origin ... 379
Chapter V—The Valley Gravels ... 380
Nature of the Gravels ... 380
Distribution and Description of the Valley Gravels ... 381
The Big Sioux River Drainage Basin ... 381
The Main Valley ... 381
Rock River Valley ... 382
Tributaries of Rock River ... 385
Area Northeast of Ellsworth, Minnesota 385
Little Rock River and Otter Creek ... 385
Area East and Southeast of Sibley ... 386
Tom Creek ... 391
Mud Creek ... 392
Small Tributaries of the Big Sioux ... 392
The Floyd River Drainage Basin ... 392
The Main Valley ... 392
Deep Creek Valley ... 394
The Little Sioux River Drainage Basin ... 395
The Headwaters of the Little Sioux Above Spencer ... 395
Tributaries of the Little Sioux from the East south to Brooke Creek ... 397
The Gravels of the Little Sioux Valley from Spencer to Its Mouth ... 398
Main Tributaries of the Little Sioux from the West Below Spencer ... 402
Willow Creek ... 402

Waterman and Murry Creeks......... 402
Mill Creek 403
Minor Tributaries of the Little Sioux in Cherokee and Woodbury Counties............ 406
The Maple River Drainage Basin................. 408
The Boyer River Drainage Basin................. 409
Fossils from the Valley Gravels........................ 409
Origin and Age of the Valley Gravels.................. 411
Chapter VI—The Nebraskan Drift.......................... 414
General Characteristics 414
Distribution and Description of Outcrops................ 418
A Grooved and Striated Nebraskan-Kansan Contact Plane 424
Chapter VII—The Geologic History of Northwestern Iowa...... 430
The Bed-Rock of Northwestern Iowa................... 430
The Proterozoic—Sioux Quartzite 431
The Cretaceous 433
Geologic History of Northwestern Iowa................. 434
Pre-Pleistocene 434
Proterozoic 434
Paleozoic 436
Mesozoic 436
Pleistocene 437
Nebraskan 437
Kansan 438
Wisconsin 441
Chapter VIII—Summary and Conclusions...................... 442
Wisconsin Boundary 442
Kansan Drift 443
The Loess 443
Nebraskan Drift 444
Drainage Changes 444
Interbedding of Gravel and Till...................... 444
Gravel Bowlders and Gravel Hills...................... 445
The Valley Gravels.................................. 445

THE PLEISTOCENE GEOLOGY OF NORTHWESTERN IOWA

Introduction

The term, northwestern Iowa, as used in this report includes twelve entire counties and halves of four other counties; four rows from north to south, and three and one-half rows from west to east. The names and relative locations of these counties are given in figure 25. This region has an area of about 9000 square miles, about half of which was studied in considerable

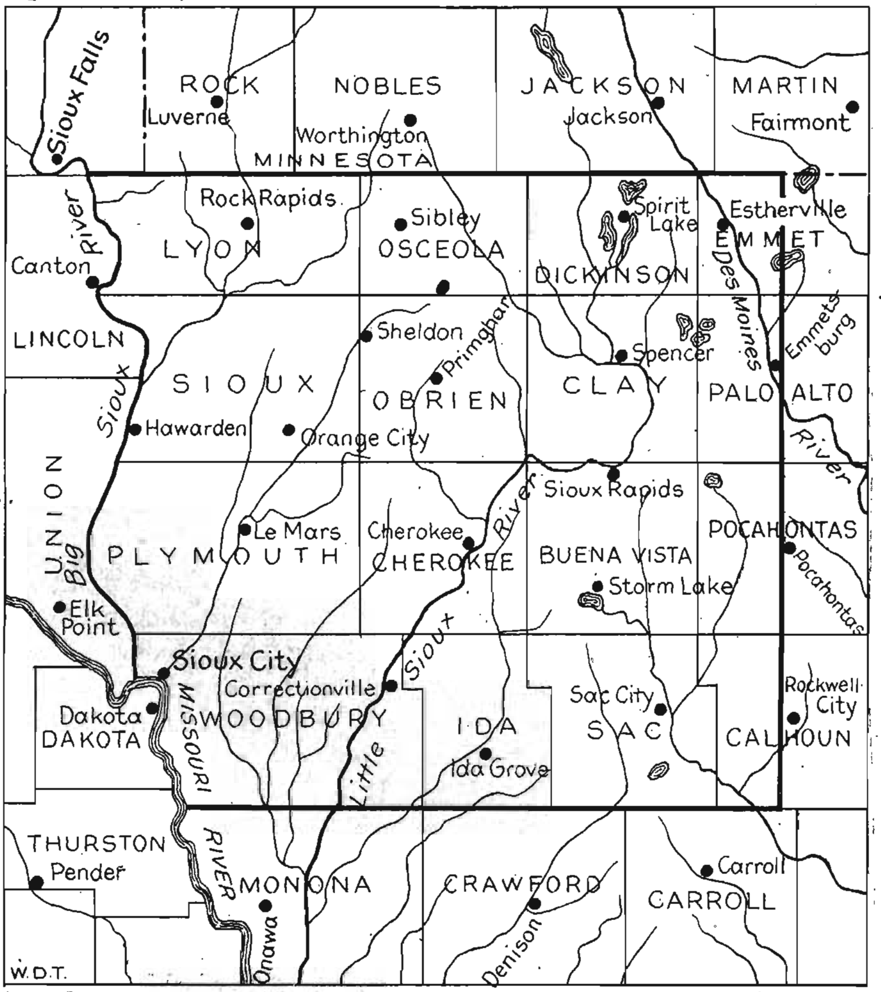


FIG. 25. ... counties and principal towns. The area treated in this report is enclosed within the heavy lines.

detail, while the remainder was covered in reconnoissance. The work also extended into the adjoining counties on the east and south and the contiguous portions of Minnesota and South Dakota, and the report will deal briefly with these areas.

The various counties of northwestern Iowa, except Calhoun county, have been studied and reported upon previously by members of the Iowa Geological Survey.[1] However, a study of these reports and the maps which accompany them will show that there were many changes of opinion during the progress of the work, and in most cases the earlier work was not revised to fit the later interpretations. Moreover, the problems of the region are largely problems involving northwestern Iowa as a whole, and hence the county-unit method of work is not suited to the region.

The work of the writer has been, therefore, of the nature of a revision and correlation of earlier work. It was begun in the summer of 1909, by retracing the west boundary of the Des Moines lobe of the Wisconsin drift-plain in northwestern Iowa. This retracing left outside the Wisconsin drift certain nearly level areas, the age of which had been variously interpreted and which it had been thought might be Wisconsin. The field work was then continued through the season of 1910, and parts of 1911, 1913 and 1916 in a study of the region west of the Wisconsin drift-boundary. This study carried the field of investigation westward to the west border of the state, and some correlation work was done in South Dakota to the west and in Minnesota to the north.

The author desires here to acknowledge his indebtedness to Professor George F. Kay, under whom, as Director of the Iowa Geological Survey, the work was completed, and to the late Professor Samuel Calvin under whose charge the work was begun; also to Mr. Frank Leverett of the United States Geological Survey, to Professors Macbride and Shimek of the Iowa Geological Survey and to Dr. James H. Lees, Assistant State Geologist. To a large number of citizens of northwestern Iowa, who have given data on their respective localities, the thanks of the author are due.

[1]Annual Reports of the Iowa Geol. Survey: Bain, Woodbury county, Vol. V, Plymouth county, Vol. VIII; Wilder, Lyon and Sioux counties, Vol. X; Macbride, Osceola and Dickinson counties, Vol. X, Clay and O'Brien counties, Vol. XI, Cherokee and Buena Vista counties, Vol. XII, Emmet, Palo Alto and Pocahontas counties, Vol. XV, Sac and Ida counties, Vol. XVI.

Northwestern Iowa is covered with glacial deposits, which almost completely conceal the bedrock. Three ice-sheets invaded the region. The area covered by the first (Nebraskan) was completely overridden by the second (Kansan) and the drift of the first is exposed only in valleys that have been cut through the overlying drift-sheet. The drift-sheets of the second and of the third (Wisconsin) ice invasions appear at the surface outside the valleys. The second ice-sheet and probably also the first covered the entire region, while the third invasion covered only the eastern part of the area.

The report begins (Chapter I) with a summary of the earlier work in northwestern Iowa. The several drifts of the region are then discussed in order from youngest to oldest. Chapter II treats the Wisconsin drift-region and Chapter III the Kansan drift-region with which is included the consideration of the loess. Chapters IV and V, on associated gravel deposits, follow the treatment of the Kansan drift, with which these deposits are closely connected. Chapter VI deals with the Nebraskan drift. Chapter VII traces the geologic history of northwestern Iowa and includes a short treatment of the bedrock. Chapter VIII restates the conclusions reached concerning the various subjects treated in the report.

In the discussion of several subjects of the report the material of a more detailed character is placed in smaller type, and may be omitted by the general reader.

CHAPTER I

EARLIER WORK IN NORTHWESTERN IOWA.

The earlier work in northwestern Iowa was of two classes: first, reconnoissance work, which dealt with large areas, chiefly the work of the earlier geological surveys of Iowa; second, somewhat detailed studies of individual counties or groups of counties, chiefly the work of the present Iowa Geological Survey.

WORK PRECEDING THE ORGANIZATION OF THE PRESENT IOWA GEOLOGICAL SURVEY.

The early geological work in Iowa was concerned principally with the bedrock of the eastern part of the state, and the superficial deposits were considered merely as obstructions to the observation of the bedrock. Owen ascended Iowa and Des Moines rivers until he passed beyond the regions of bedrock outcrops, and then turned back.[2] He shows on page 104 a sketch of the topography found on the upper course of the Iowa river (southwestern Franklin county), labeling it "Knobby drift region of northern Iowa", and states that the region is a "barren region of drift knolls." Concerning the upper part of the Des Moines river valley he says, "Beyond this (northern Webster county) the stream enters and meanders through an open prairie country, presenting to view low drift knolls" (p. 128). A party of the same survey exploring the southern tributaries of Minnesota river had found that these streams likewise head on a drift-covered region, and so it was "inferred that these barren drift knolls extend beyond the northern boundary of Iowa, covering the whole water-shed" of northern Iowa and southern Minnesota (page 104).

In the report of Hall and Whitney[3] there is very little reference to northwestern Iowa. On page 14 is this statement, "The most striking feature in the topography of the northwest is the predominance of prairies, a name--now universally adopted, to designate natural grass-land." The prairies were attributed (pages 24 to 26) to their close, fine-grained soil which was thought to be inhospitable to trees and this soil was supposed to have been accumulated in a great lake which once covered the region of the prairies.

The first comprehensive and general work on the Geology of Iowa was that by Dr. C. A. White.[4] In this report, northwestern Iowa is considered in the general treatment of the "Physical Geography and Surface Geology" (Vol. I, part 1), and in the special treatment of "Northwestern Iowa" (Vol. II, part 1, chap.

[2]Owen, D. D., Geology of Wisconsin, Iowa and Minnesota, pp. 104 and 128, 1852.
[3]Hall and Whitney. Report on the Geological Survey of the State of Iowa, Vols. I and II, 1858.
[4]White, C. A., Report on the Geological Survey of the State of Iowa, Vols. I and II, 1870.

2). The superficial deposits of the state were interpreted as the product of glacial action, but the idea of more than one glacial epoch had not yet been advanced. Northwestern Iowa is described as "generally very well drained, although a large part of it is occupied by an unusually flat portion of the Great Watershed" (Vol II, page 201).

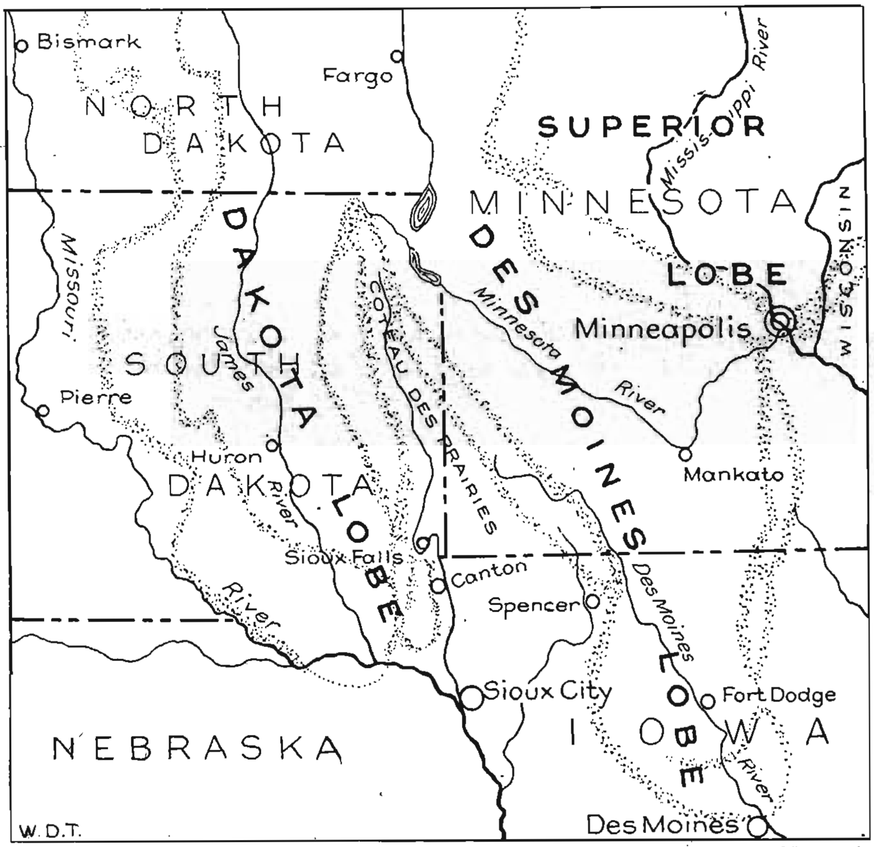


FIG. 26. Map showing the extent of the Des Moines and Dakota lobes of the Wisconsin ice-sheet. After Chamberlin, U. S. Geol. Survey, Third Ann. Rept., Plate 35.

Professor Chamberlin, during the seventies of the last century, separated the glacial deposits of America into two series, and the work of Chamberlin, Upham and Todd outlined the extent of the Minnesota-Des Moines Valley and the Dakota Valley glaciers. In his "Preliminary paper on the Terminal Moraine of the Second Glacial Epoch"[5] Professor Chamberlin

[5]Chamberlin, T. C., Terminal Moraine of the Second Glacial Epoch: U. S. Geol. Survey Third Ann. Report, pp. 291-404, 1883.

mapped the extent of and described the moraines of these lobes (figure 26). The west border of the Des Moines lobe he described as extending northward through Carroll, Sac, Buena Vista, Clay and Dickinson counties in Iowa, and continuing to the northwest through southwestern Minnesota to the head of the Coteau des Prairies. The east border of the Dakota lobe he placed west of Big Sioux river, leaving the northwest corner of Iowa as a part of the older drift-plain lying between the two lobes of the younger drift-plain.

WORK SINCE THE ORGANIZATION OF THE PRESENT IOWA GEOLOGICAL SURVEY.

The present Iowa Geological Survey was organized in 1892, and the first report of this Survey which treats of the glacial deposits of any part of northwestern Iowa is that on Woodbury county, by H. F. Bain.[6] Bain describes the topography found in the region of thick loess deposit along the Missouri as rugged (pages 248 to 249), but concerning the drift-plain farther inland he says that it is characterized by "long, low, rolling swells, flattening out into occasional broad areas of absolute level." He assigned the drift to the Kansan epoch.

In "The Great Ice Age"[7] Professor Chamberlin shows a belt of Iowan drift-plain twenty-five to thirty miles wide, extending along the whole of the western border of the Des Moines lobe. This belt includes in northwestern Iowa most of the second tier of counties east of Big Sioux and Missouri rivers. The region to the west of this Iowan belt is mapped as Kansan.

In 1896, H. F. Bain provisionally correlated the drift of northwestern Iowa, west of the Wisconsin lobe, with the Iowan drift of eastern Iowa,[8] and published as Plate XXVIII of his report, a Pleistocene map of Iowa which shows the southern "Probable Limit of Iowan Drift" in northwestern Iowa as leaving the Wisconsin moraine in northern Sac county and extending westward along the line between Ida and Cherokee counties and through southern Plymouth county to Big Sioux river about ten miles above its mouth.

[6]Bain, H. F., Geology of Woodbury County: Iowa Geol. Survey, Vol. V, pp 241-299, 1896.

[7]Chamberlin, T. C., The Great Ice Age (Geikie), Pl. 15, 1894.

[8]Bain, H. F., Relations of the Wisconsin and Kansan Drift Sheets in Central Iowa: Iowa Geol. Survey, Vol. VI, p. 462, and Pl. 28, 1897. Calvin, S., Administrative Report: Iowa Geol. Survey, Vol. VII, p. 20, 1897.

The study of Plymouth county by Bain in 1897 was the first detailed study of the drift deposits of any part of northwestern Iowa. In this report[9] Bain discussed the lack of weathering and leaching of the drift, and the limited erosion which the region has undergone, and decided that " all the classes of evidence noted united in showing that the drift cannot be Kansan" (page 349). Either an Illinoian or an Iowan age was considered more probable, and between these two he did not decide definitely but left it "for the present", in the Iowan, to which it "has already been provisionally referred". The southern border of this Iowan area he placed farther south than on his earlier map[10] and wrote concerning it (page 351), "it can only be outlined as running from Carroll northwest through the northern tier of townships in Crawford county". Subsequent investigation evidently did not bear out this statement for in his report on Carroll county[11] Bain mapped all the area west of the Wisconsin boundary as Kansan drift.

In 1899 Professor Wilder reported on Lyon and Sioux counties.[12] The age of the loess-covered drift was still undecided, but on the map he labeled it Kansan, and after a long discussion of the subject (pages 123 to 132) concluded with the following statement, "Considering everything, it seems safer to consider the loess-covered drift of Lyon and Sioux counties as Kansan until something is found in the way of a southern boundary to distinguish it from the recognized Kansan farther south."

Professor Wilder mapped the extreme northeast corner of Lyon county as part of the Des Moines lobe of the Wisconsin drift-plain, and an area three to five miles wide, to the south and west of this, as Wisconsin outwash gravels, with great trains of the same continuing southward along the stream courses (figure 27). He also decided that the east border of the Dakota lobe pushed across Big Sioux river and occupied a narrow strip along the east side of the valley in western Lyon county. This interpretation makes the distance between the Des Moines and Dakota

[9]Bain, H. F., Geology of Plymouth County: Iowa Geol. Survey, Vol. VIII, pp. 315-366, 1898.

[10]Iowa Geol. Survey, Vol. VI, Pl. XXVIII, 1897.

[11]Bain, H. F., Geology of Carroll County: Iowa Geol. Survey, Vol. IX, pp. 49-107, 1899.

[12]Wilder, F. A., Geology of Lyon and Sioux Counties: Iowa Geol. Survey, Vol. X, pp. 85-184, 1900.

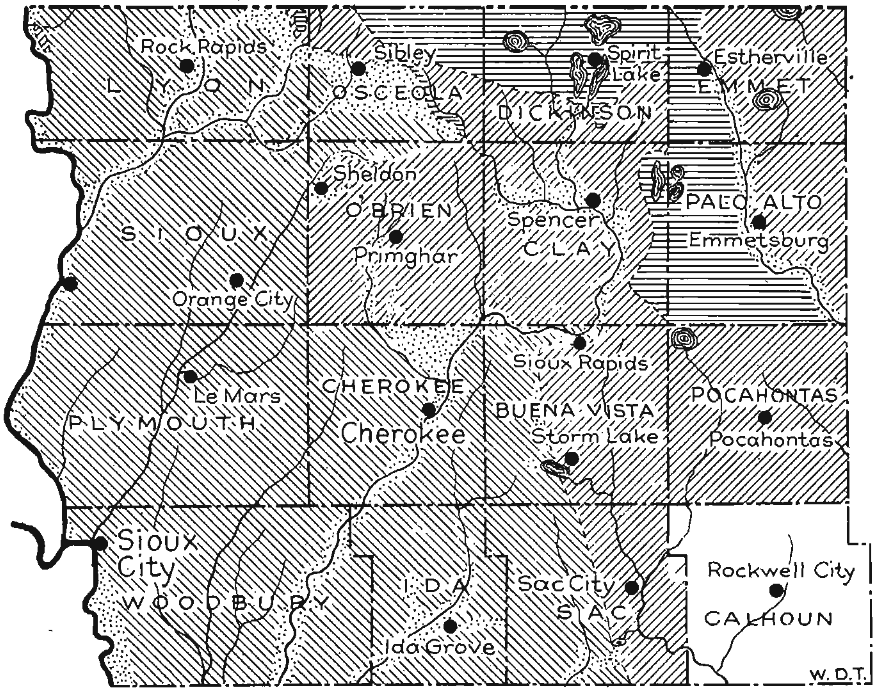
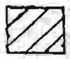


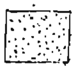
FIG. 27. A map of northwestern Iowa made by compiling the Pleistocene maps in the county reports.

"Kansan drift" of Woodbury, Ida and Sac counties; "Loess overlying older drift (Kansan)" of Cherokee and Buena Vista counties; "Loess overlying Kansan" of Lyon and Sioux counties; "Loess overlying older drift" of Osceola and O'Brien counties; "Provisionally Iowan" of Plymouth county.



"Wisconsin Drift" of Lyon, Osceola, Dickinson, O'Brien, Palo Alto, Buena Vista, Pocahontas and Sac counties; "Wisconsin Drift Plain" of Clay county; "Wisconsin Plain" of Emmet county.

"Altamont Moraine" of Lyon county; "Wisconsin Moraine" of Osceola county; "Knobby Drift, Morainic" of Dickinson county; "Knobby Drift" of Clay county; "Wisconsin Drift, affected by Morainic Knobs" of Emmet county; "Morainic Deposits" of Palo Alto county.



"Wisconsin Partially Stratified" of Lyon, Sioux, Osceola, Dickinson and Clay counties; "Wisconsin Gravel Train" of O'Brien county; "Wisconsin Overwash Gravels" of Cherokee county; "Alluvial Deposits" of Emmet, Palo Alto, Cherokee, Buena Vista and Sac counties; "Alluvium" of Ida county.

lobes less than thirty-five miles in northern Lyon county. Both these areas of Wisconsin drift are shown on the map of Lyon county and discussed in that report (pages 94 to 95, 132 to 143).

The same year Professor Macbride reported on Osceola and Dickinson counties[13] and continued the mapping units of Lyon

[13]Macbride, T. H., Geology of Osceola and Dickinson Counties: Iowa. Geol. Survey, Vol. X, pp. 185-239, 1900.

county eastward into Osceola county (figure 27). The northern part of Dickinson county, the northeast third of Osceola county, and a narrow belt along the west bluff of Ocheyedan river were mapped as "Knobby Drift" or "Wisconsin Moraine". The southern third of Dickinson county and smaller areas in southeastern and northwestern Osceola county were mapped as "Wisconsin Drift", outside the distinctly knobby areas, thus constituting extra-morainic Wisconsin drift. The area of "Wisconsin Partially Stratified" which was continued from Lyon county into Osceola, was mapped as broadening out in the central part of the county to an area six to eight miles across and then narrowing again to two to three miles where it strikes the south border of the county. The southwest corner of Osceola county was mapped as loess-covered older drift, and was referred provisionally to the Kansan epoch, (page 218).

The following year (1900) Professor Macbride reported on Clay and O'Brien counties.[14] Clay county was mapped as "Wisconsin Drift" except for a belt of "Knobby Drift" along the east border of the county and some large gravel areas along the streams (figure 27). The narrow belt of "Wisconsin Moraine", mapped along the west bluff of the Ocheyedan valley in Osceola county, and there considered a part of the Altamont moraine,[15] was not continued southward into O'Brien and Clay counties. This is true also of the area of "Wisconsin Partially Stratified". The whole of O'Brien county was mapped as "Wisconsin Drift" except a narrow wedge-shaped area in the northwest corner of the county which apparently was assigned to the "Older Drift" in order to match up with the map of Osceola county made the previous year. The "Wisconsin Drift" of the O'Brien county map joins along the west line of the county with the "Kansan Drift" of the Sioux county map.

This mapping by Professor Macbride created a large area of "Wisconsin Drift" in northwestern Iowa lying outside the Wisconsin moraine, an extra-morainic Wisconsin drift. In the same volume with the report on Clay and O'Brien counties there appeared a "Preliminary Outline Map of the Drift Sheets of

[14]Macbride, T. H., Geology of Clay and O'Brien Counties: Iowa Geol. Survey, Vol. XI, pp. 461-508, 1901.
[15]Iowa Geol. Survey, Vol. X, p. 202 and Osceola County map, 1900.

Iowa'',[16] which also mapped O'Brien and Clay counties together with parts of Lyon, Osceola, Dickinson, Cherokee and Buena Vista counties as ''Wisconsin'' lying outside the ''Wisconsin Moraine''.

Subsequent work to the south evidently did not bear out the earlier conclusions concerning this extra-morainic Wisconsin area for in the report on Cherokee and Buena Vista counties[17] Cherokee county, to the south of O'Brien, was mapped as ''Older Drift (Kansan)'' except for a triangular area between Mill creek and the Little Sioux which was called ''Wisconsin Overwash Gravel'' (figure 27). The west part of Buena Vista county also was mapped as Kansan drift, which consequently abuts on the north against the ''Wisconsin Drift'' area of the Clay county map. The central and east parts of Buena Vista county were mapped as ''Wisconsin Drift'', but without a morainic belt along the boundary.

The previous assignment of the drift of O'Brien and Clay counties to the Wisconsin epoch was questioned (page 319), with the suggestion that it might prove to be earlier Wisconsin or even older. The problem was evidently considered the same as that in Plymouth county to which report ''the reader is referred.'' In the Plymouth county report the drift had been provisionally referred to the Iowan epoch.[18]

As a part of the report on Cherokee and Buena Vista counties Professor Macbride discussed ''The Margin of the Wisconsin Drift''[19] in northwestern Iowa, and mapped the course of the Altamont moraine (figure 28), a course which shows little relation to that of the same moraine on the county maps north of Buena Vista county. The age of the drift ouside the moraine was not discussed but since this drift was placed outside the Altamont moraine one would infer that it was considered as the drift of a separate ice-sheet, earlier than the late Wisconsin. However, this idea is not borne out by the next ''Preliminary Outline Map of the Drift Sheets of Iowa'',[20] which shows a considerable area of ''Wisconsin'' west of the ''Wisconsin Mor-

[16]Iowa Geol. Survey, Vol. XI, Pl. 2, 1901.
[17]Macbride, T. H., Geology of Cherokee and Buena Vista Counties: Iowa Geol. Survey, Vol. XII, pp. 303-353, 1902.
[18]Iowa Geol. Survey, Vol. VIII, pp. 341-351, 1898.
[19]Iowa Geol. Survey, Vol. XII, pp. 325-338, 1902.
[20]Iowa Geol. Survey, Vol. XIV, Pl. III, 1904.

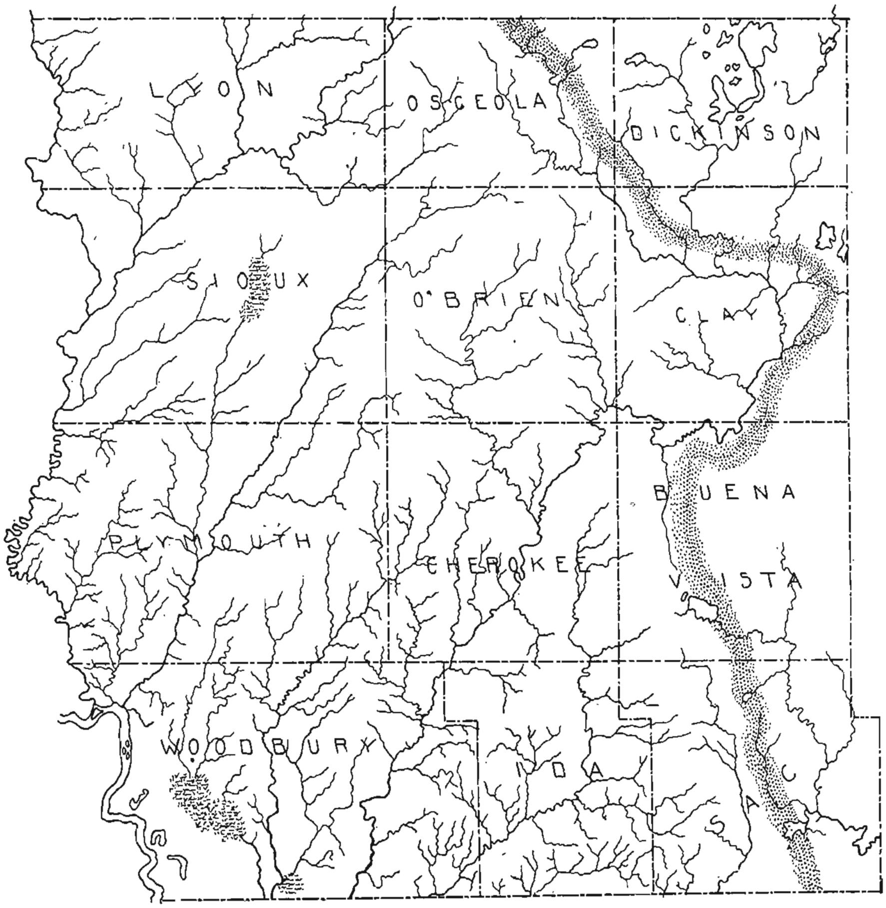


FIG. 28. Map by Professor Macbride showing the location of the Altamont moraine in northwestern Iowa. (From Iowa Geological Survey, volume XII, p. 329.)

aine." The western boundary of the "Wisconsin" area is farther east than on the earlier map,[21] but the area still includes all of Clay county west of the moraine, the larger parts of Osceola and O'Brien counties and parts of Lyon, Dickinson, Cherokee and Buena Vista counties.

The work of Professor Macbride in Sac and Ida counties[22] connected up his tracing of the Wisconsin drift boundary with the work of Bain in Carroll county to the south. The Wisconsin boundary was mapped as passing southward across central Sac

[21]Iowa Geol. Survey, Vol. XI, Pl. II, 1901.
[22]Macbride, T. H., Geology of Sac and Ida Counties: Iowa Geol. Survey, Vol. XVI, pp. 511-562, 1906.

county, dividing the county almost equally between the Wisconsin and the Kansan drifts (figure 27). The whole of Ida county was mapped as Kansan drift.

Professor Macbride also reported on Emmet, Palo Alto and Pocahontas counties.[22a] These counties are entirely within the Wisconsin drift-region. Western Emmet and Palo Alto counties were mapped as "Wisconsin Moraine" and the east parts of the counties as "Wisconsin Drift", the boundary between the two divisions being the Des Moines river valley except in the northwest township of Emmet county where the morainic area crosses to the east of the valley (figure 27). Pocahontas county to the south was assigned entirely to the "Wisconsin Drift" area, which, along the north line of the county, for more than twenty miles, abuts against the "Wisconsin Moraine" of Palo Alto county. Also along most of the west line of Emmet county and for a few miles in the northwest and southwest corners of Palo Alto county, the west lines of these counties form the boundary between the "Wisconsin Moraine" and the "Wisconsin Drift" of Dickinson and Clay counties (figure 27).

Even a cursory examination of the county reports noted above will show the lack of agreement of the county maps (figure 27) and frequent contradictions in the texts, many of which would have been avoided if larger areas had been studied before the reports were published. With the accumulation of new evidence new interpretations were adopted without showing that the earlier ones were no longer tenable. In some cases divisions were placed upon maps without discussion, and boundaries were mapped without being traced in the text, and without discussion of the characters upon which the boundaries are based. This makes it very hard to determine just what the final opinion was on certain points.

[22a] Macbride. T. H. Geology of Emmet, Palo Alto and Pocahontas Counties: Iowa Geol. Survey, Vol. XV, pp. 227-276, 1905.

CHAPTER II

THE WISCONSIN DRIFT-REGION.

During the Wisconsin Glacial epoch a great lobe of ice from the Keewatin center of central Canada occupied the basin of the Red River of the North, and advancing southward divided into two lobes at the head of the Coteau des Prairies in northeastern South Dakota. One lobe (Dakota lobe) continued southward down the James river drainage basin of eastern South Dakota, and reached the southeast corner of that state. The other (Minnesota-Des Moines lobe), passed southeastward down the Minnesota river valley to its bend in southcentral Minnesota, and then pushed southward over the divide into the Des Moines river valley, and across northcentral Iowa to Des Moines. The general extent and location of these lobes are shown in figure 26. Within the region considered in this report northeastern Osceola, most of Dickinson, and eastern Clay, Buena Vista and Sac counties belong to this drift-region (Plate XV).

General Characteristics

Topography.—The Wisconsin drift-region of northern Iowa is characterized by a distinctly glacial topography. The margins of the Wisconsin drift both on the east and on the west are more or less well developed terminal moraines, but most of this drift-region is a level or gently undulating plain. Within our area, the terminal moraine topography is well developed around the lakes of Dickinson county, in eastern Clay county, and in western Palo Alto and Emmet counties. Weaker terminal moraine is found in northeastern Osceola county. To the south in Buena Vista and Sac counties the morainic topography is faint or lacking altogether and the slightly rolling ground-moraine continues to the Wisconsin drift-boundary.

Most of the topographic features of the Wisconsin drift are constructional, consisting of moundlike hills and broad swales interspersed with undrained depressions. The relief varies from place to place, being forty to sixty feet in half a mile in the more rugged terminal moraine, and only five to ten feet in half a mile in some of the level ground moraine. The drainage of the region is youthful and lakes and marshes are numerous. Most of the broad swales have streams, but these streams did not make the valleys which they occupy. They made only the narrow channels in which they flow. Some of the larger streams have cut narrow, steep-sided valleys in the Wisconsin drift-plain, but even these streams have formed the topography of only a small part of the area they drain.

Drift.—The Wisconsin drift is light yellowish gray clay, loose, and sufficiently sandy to crumble when crushed in the hand. It contains many pebbles and bowlders which, locally in the morainic areas, make up a considerable part of the whole. Bowlders lie on the surface at many places and pebbles and gritty material appear in the soil. The till is calcareous, even to the surface, and at many places concretions of calcium carbonate are present for a few feet below the surface. The till is practically unaltered except for the incomplete distintegration of the coarse-grained igneous pebbles. In the deeper exposures the color of the till is somewhat darker than that near the surface.

The West Boundary

The position of the Wisconsin drift-boundary is one of the problems concerning which there has been much indecision, and the course as traced by the writer is, in part, quite different from that located by earlier work. This subject therefore, is treated in considerable detail. The Wisconsin drift-region to the north and east of the boundary was studied only in so far as it was thought to bear upon the interpretation of the features along the boundary.

The general results of previous work in northwestern Iowa have been given in Chapter I but that part of the work which has had to do directly with the Wisconsin drift-boundary is summarized here.

EARLIER WORK ON THE WISCONSIN BOUNDARY.

In his report on the Terminal Moraine of the Second Glacial Epoch, Professor Chamberlin described the moraine of the west side of the Des Moines lobe as extending from Des Moines "northwesterly along the middle Raccoon River, diagonally through northeastern Guthrie and central Carroll into Sac county, where it turns more northerly and extends to the southern part of Buena Vista county. Here it makes a strange easterly detour, passing curvingly through eastern Clay, central Dickinson and northeastern Osceola counties."[23]

After the organization of the present Iowa Geological Survey, H. F. Bain did considerable work along the southern portion of the western boundary of the Des Moines lobe, to the south of our region.[24] His work verified, in general, the earlier tracing by Upham and Chamberlin.

In 1898 Mr. Frank Leverett, while on a short inspection trip of the drift formations of northwestern Iowa "traced the morainic hills of the Wisconsin drift from southwestern Minnesota into the northeast corner of Lyon county".[25] The following year Wilder mapped this northeast corner of Lyon county as Wisconsin drift with patches of Altamont moraine,[26] and Macbride, continuing the same mapping units into Osceola and Dickinson counties,[27] extended the Wisconsin drift border eastward across western Osceola county just north of Sibley and Allendorf to the west bluff of the Ocheyedan river valley and then southeastward along the west bluff of this valley to the O'Brien county line (figure 27). Then followed the report on Clay and O'Brien counties,[28] which shifted the boundary to or beyond the west line of O'Brien county, and the Cherokee and Buena Vista counties report,[29] which again shifted it eastward to western Buena Vista county, and the Sac and Ida counties report,[29a] which continued the boundary southward through central Sac county.

After Professor Macbride had studied the Wisconsin drift margin from Carroll county northward to the state line he revised his previous conclusions and, in the report on Cherokee and Buena Vista counties, he discussed "The Margin of the Wis-

[23]U. S. Geol. Survey Third Ann. Report, p. 389, 1883.
[24]Annual Reports of the Iowa Geol. Survey: Bain, H. F. Relations of the Wisconsin and Kansan Drift Sheets in central Iowa, Vol. VI; Geology of Polk County, Vol. VII; Guthrie County, Vol. VII; Carroll County, Vol. IX.
[25]Bain, H. F., Administrative Report: Iowa Geol. Survey, Vol. IX, p. 26, 1899.
[26]Iowa Geol. Survey, Vol. X, pp. 132-135 and map p. 119, 1900.
[27]Iowa Geol. Survey, Vol. X. map p. 209, 1900.
[28]Iowa Geol. Survey, Vol. XI, map p. 491, 1901.
[29]Iowa Geol. Survey, Vol. XII, map, p. 355, 1902.
[29a]Iowa Geol. Survey, Vol. XVI, pp. 535-539 and map, p. 537, 1906.

consin Drift",[30] and mapped the course of the Altamont moraine from Carroll county northward to the state line (figure 28). This course is northward through Sac and Buena Vista counties to the Little Sioux valley east of the mouth of Brooke creek. It then follows the south bank of the Little Sioux valley eastward past Sioux Rapids to Gillett Grove in southeastern Clay County. From here it bears northeast to a point east of the town of Dickens, where, bending sharply to the west, it follows the north slope of the Little Sioux valley westward, passing just north of Spencer. Crossing the Little Sioux just above its union with the Ocheyedan the boundary follows the northeast slope of the latter valley through northwestern Clay and eastern Osceola counties to the state line. The course of this boundary is merely stated and the evidence upon which it is based is not given. This is Professor Macbride's final statement on the Wisconsin drift margin and thus the question stood when the writer took up the revision study in 1909.

CRITERIA FOR DISTINGUISHING THE WISCONSIN BOUNDARY.

The separation of the Wisconsin drift-region from the older drift-region to the west is based chiefly on physiographic characters and the boundary is first of all a physiographic boundary. Differences in the character of the drift and in its surface covering are contributory lines of evidence, useful when available; but when these appear to fail, physiographic differences must be used as the basis for the separation. And even with this criterion, extreme care in observation, and appreciation of the significance of certain slight differences are required.

As stated on page 251, the topography of the Wisconsin drift is largely constructional. Along part of the boundary these constructional features are prominent, being morainic hills, and depressions that are occupied by lakes and marshes. Elsewhere, because of the slight relief, the constructional features are not prominent, but they may be detected by careful observation. The most prominent topographic feature of the region west of the Wisconsin drift-boundary is its valleys, and the drainage of this region is complete. The small undrained depressions which

[30] Iowa Geol. Survey, Vol. XII, pp. 325-338 and Fig. 58, 1902.

characterize the Wisconsin drift are entirely absent. These depressions are an important character in determining the location of the Wisconsin drift-boundary.

The Wisconsin till is more sandy and therefore less compact than the Kansan till of the region to the west. When it is crushed in the hand, it crumbles to a mealy clay, while the older till as a rule is plastic. The Wisconsin till also contains a larger number of pebbles, cobbles and bowlders. Its color is gray, while the older till is buff to yellow. The differences are not such that every exposure along the boundary can be identified as Wisconsin or Kansan till, but many exposures can be so identified. Some of these will be noted in the discussion of the Wisconsin drift-boundary (pages 255 to 292).

The Wisconsin drift comes to the surface and there are pebbles and grit in the soil and bowlders on the surface. A thin mantle of leached loess covers the region west of the Wisconsin drift and conceals the till except in the more rugged parts. The Wisconsin till is practically unaltered and calcareous to the surface, but this is almost equally true for the Kansan till. The loess overlying the Kansan till, however, is at most places leached.

RETRACING THE WISCONSIN BOUNDARY.

The Boundary South of Sac County.—This report deals principally with that part of the Wisconsin drift boundary north of the south line of Sac county; but for the sake of comparison and in order to study the criteria upon which the separation was made, the boundary was examined at several places south of Sac county, in Carroll county, and even farther southeast as far as Des Moines. For most of the distance the boundary follows the northeast slope of Middle Raccoon river valley. This valley, except possibly in part of Carroll county, was a pre-Wisconsin feature and the ice-margin at some places pushed down to the edge of the stream, and was at no place more than two miles away. The stream was crowded over against the southwest slope by the ice and by the debris which came down from the ice-margin, and locally may have been diverted from its valley. The ice, however, did not fill the valley for any considerable distance.

At a few places along this valley, outwash materials came down from the ice-front to the north and were deposited on the valley slope or in the valley, where they now form benches (terraces). On the whole, however, there is very little outwash material, and although this valley received the drainage of eighty to ninety miles of the ice-margin it has no continuous gravel benches.

Northeast of the Middle Raccoon valley, youthful drift topography is continuous, while to the southwest, the maturely dissected topography of the Kansan drift-plain prevails. The topographic contrast of the two regions is pronounced through this southern district and in most places the location of the boundary is well defined, even where a valley does not mark the boundary. Furthermore, the Kansan drift has a weathered surface zone while the Wisconsin drift is fresh throughout, and most of the Kansan drift is covered with a veneer of loess, while the Wisconsin drift is without such cover.

From the South Line of Sac County to the Little Sioux Valley at the Mouth of Brooke Creek.—The general course of the boundary across Sac and Buena Vista counties is very straight with a direction 18° west of north (Plate XV). So uniform is this course, that if a straight line were drawn connecting the point at which the boundary crosses the south line of Sac county with the mouth of Brooke creek, it would nowhere be two miles from the actual boundary, and with the exception of the region south of Wall lake outlet, nowhere so much as one mile.

From the south line of Sac county the Wisconsin drift-boundary extends northwestward along the valley of a small creek to the Wall lake outlet (Plate XV). Throughout this distance the Wisconsin drift topography comes up to the east side of this little valley, while it is not present on the west. This course just south of the outlet is about one and one-half miles farther west than that traced by Professor Macbride.

Three miles north of the south line of Sac county a flat-bottomed marshy valley, about one mile wide and ninety to one hundred feet below the upland to the south, leads westward from the margin of the Wisconsin drift to the Boyer river valley, a distance of three to four miles. This valley is known as the Wall lake outlet. It is not now followed by any stream, but apparently was an outlet for drainage from the Wisconsin ice-margin westward to the Boyer valley. From its east end, a marshy flat stretches northward two miles over a low divide to Wall lake, along a course that was followed by waters draining southward along the ice-margin to the Wall lake outlet.

Where it crosses the Wall lake outlet, the Wisconsin boundary is offset a mile to the east. Thence it passes north through Lake View and west of north through western Wall Lake, eastern Boyer Valley and western Delaware townships of Sac county, and through eastern Hayes township of Buena Vista county to the southeast corner of Storm lake (Plate XV). A belt one to two miles wide along the margin of the Wisconsin drift-plain from Wall lake to the north border of Sac county has a moderately well developed terminal moraine topography, with bowlder-strewn hummocks and saucer-shaped depressions occupied by ponds and marshes.

East of the margin the region grades into a slightly rolling glacial plain, which continues up to the edge of the narrow steep-sided Raccoon river valley. Beyond this valley a slightly rolling to flat ground moraine topography characterizes eastern Sac county and continues across Calhoun county.

West of the Wisconsin drift-boundary, the region is completely drained, and presents a topography marked by broad valleys and undulating slopes. In general the region just to the west of the boundary from Wall lake outlet to Storm lake is higher than the Wisconsin drift-margin to the east.

North of Storm lake the boundary passes just east of the town of Storm Lake, and from here the valley of Brooke creek forms the boundary northward through Washington, Elk and Brooke townships to the valley of Little Sioux river (Plate XV). The contrast of the topography on opposite sides of Brooke creek in Elk township is striking. On the east is a slightly rolling glacial plain, with its rounded hills and occasional marshes, continuing up to the very edge of the valley, which at some points is hidden from view even at a distance of half a mile. On the west there is a general eastward slope cut by parallel valleys which head westward toward the broad, high area of central Elk and Brooke townships.

The boundary of the Wisconsin drift crosses the south line of Sac county near the quarter-corner on the south of section 34, Viola township, and extends northwestward along the valley of a small creek through the southwest quarter of section 34, the northeast quarter of section 33, the southwest quarter of section 28, the central part of section 29, the west part of section 20 and the southwest quarter of section 17 to the Wall lake outlet (Plate XV). The topography just east of the valley is not so definite and positive as farther east, but the features that characterize the Wisconsin drift-plain are present. In the central part of section 20, 100 yards east of the valley there is one small depression that will hold water and two others are present in the northeast quarter of section 29. Also the soil is sandy and contains pebbles.

This course through sections 29 and 20 is about one and one-half miles farther west than that traced by Professor Macbride, which extends northward through the west parts of sections 34 and 27 and the east part of section 21. East of the line traced by Professor Macbride the region is plainly Wisconsin, being a moderately rolling glacial plain with marsh areas and a few hummocky hills. Here all the pre-Wisconsin erosional features were completely obliterated. There is, however, no significant change along this course traced by Professor Macbride, and the west parts of sections 28 and 21 and the east parts of sections 29 and 20 were covered by the Wisconsin ice long enough to develop the positive glacial features noted above, but not enough drift was deposited to obliterate completely the pre-Wisconsin erosional features.

The till well within the Wisconsin area is sandy yellowish gray clay. Certain exposures along the small valley in section 20 show till that is neither typical Wisconsin nor Kansan. An exposure just west of the northeast corner of section 30, just outside the area that could be called Wisconsin on the basis of topography, may be Wisconsin till, and, considered in connection with some exposures on the east line of the northeast quarter of section 19, and some bowlders on the north line of 19, suggests that the Wisconsin ice may have crossed temporarily the valley of section 20, and occupied the east part of section 19. In this case the boundary follows a small creek valley that extends from north to south across the central part of section 19, and then passes across the northeast quarter of section 30 and the northwest quarter of section 29, to the valley in the central part of section 29. This change of the boundary could not be made on the basis of topography.

From Wall lake outlet northward within a few miles of the north border of Sac county, the boundary is along a depression, apparently a pre-Wisconsin valley, parallel with the Boyer river valley to the west. The depression is followed along most of its length by Indian creek, which flows southward, and during the time of ice occupancy it led the marginal drainage southward, past Lake View, to the head of the Wall lake outlet, which opened westward to Boyer river. This valley drained twelve to fifteen miles of the ice-margin, and the great deposits of gravel at the west end of Wall lake and south of Lake View were deposited by its waters. The east slope of Indian creek valley has a glacial topography with gravelly mounds and swamps; but the west slope is even and rises gradually to the rounded divide, fifty to sixty feet higher, which separates Indian creek from Boyer river. Farther north the ice seems to have climbed higher up this slope on the west, until in western Delaware township the divide was almost overridden, and, locally, drainage may have passed over it to Boyer river. Farther north, in section 36 of Hayes township of Buena Vista county, a steep-sided valley leaves the Wisconsin margin and extends westward through the divide. A small area of the Wisconsin drift-plain now drains westward through this valley to the headwaters of the Boyer, but when the Wisconsin ice was present, the drainage of several miles of the ice-front, from Storm Lake on the north to the county line on the south, probably drained westward through this valley.

Storm lake lies just outside the Wisconsin drift-boundary and occupies a part of a stream valley which in pre-Wisconsin time headed westward on the slope of the great watershed at Alta, and continued eastward to some western tributary of the Des Moines. When the Wisconsin ice-front lay across this valley, an ice-margin lake was formed, and when the ice withdrew, the old valley had been dammed by the morainic deposits to such an extent that the basin of Storm lake was formed. The ice-margin lake probably drained southward along the edge of the ice for three miles to the head of the valley described above, which leads westward through the divide to the headwaters of Boyer river. The present outlet from the southeast corner of the lake follows this old course southward for about two miles, and then turns eastward across the Wisconsin drift-plain to Raccoon river.

Storm lake is three miles long and one and one-half miles wide. The water is nowhere more than fifteen deep, and considerable areas near the shore are only a few feet deep, being dry or marshy in times of low water. Cliffs ten to fifteen feet high rise from the water's edge along the northwest margin of the lake, and at a few places farther east, but in general the slopes are gentle, and beaches border the lake.

Just north of Storm lake the boundary passes through the west central part of section 2, just east of town, and then northwest across section 34 and along the west line of section 27, Washington township, to the headwaters of Brooke creek in section 21. Parts of sections 28 and 33 have a slightly rolling, filled-in topography on the headwaters of some small streams. From section 21 the valley of Brooke creek forms the boundary northward through Washington, Elk and Brooke townships to the valley of Little Sioux river (Plate XV). For most of this distance the Wisconsin drift-plain on the east with its rounded hills and undrained marshes comes up to the very edge of Brooke creek valley. The east halves of section 36, Brooke township, and section 1, Elk township, just east of the valley, have a terminal moraine topography, and on the north line of section 13, Elk township, an exposure on the valley slope only eighty rods east of the creek shows Wisconsin till overlying sand. At a few places, as in the southwest part of Scott township, the ice may have stopped a short distance east of the creek on the valley slope, but even there the material washed down from the ice-margin modified the surface so that there is no typical Kansan drift topography on the east side of Brooke creek.

The exact course of the boundary in the angle between the Little Sioux and Brooke creek valleys is rather indefinite because of erosion. At the south line of section 24, Brooke township, the boundary draws away from Brooke creek and runs directly north through the centers of sections 24 and 13. Between this boundary and Brooke creek to the west the surface is much dissected into spurs projecting westward, which have a uniform level and are capped with a gravel deposit. In the southeast part of section 12 the boundary turns sharply to the east, parallel with the south bluff of the Little Sioux valley.

Along the Little Sioux Valley from Brooke Creek to Gillett Grove.—From the mouth of Brooke creek eastward and northward, the Wisconsin drift-boundary follows closely the southeast edge of the Little Sioux valley past Linn Grove and Sioux Rapids, to Gillett Grove in southeastern Clay county (Plate XV).

This is one of the most peculiar and interesting parts of the whole boundary. Extending in a southwesterly direction, the boundary touches the valley at Gillett Grove and then for about twenty-five miles follows the edge of the valley, passing, in that distance only nine miles to the south and fully twelve miles to the west. The ice pushed westward into the loop of the river in Herdland township, Clay county, and then westward along the south side of the valley past Sioux Rapids and Linn Grove to eastern Brooke township. It even pushed back northward into the loops at Sioux Rapids and in section 3, Barnes township. Making all possible allowances for the southward retreat of the valley-wall in the southward loops to the east and west of Sioux Rapids, it still seems evident that the direction of ice motion was really somewhat northward into these loops, especially in the case of the one in Barnes township. It would be interesting to have a record of the path of the ice which came out to the boundary in northern Barnes township, for at the margin in sections 10 and 3 it must have had a direction of motion nearly opposite to that which it had at the north line of the state.

This westward thrust carried the ice into the angle formed by the Brooke and Little Sioux valleys, where the boundary turns abruptly at almost a right angle. The force which caused this westward thrust of the ice seems to have been fully spent when northwestern Buena Vista county was reached, for here the boundary changes direction to east of south and holds this course southward through Buena Vista, Sac and Carroll counties.

What the course of the boundary would have been between Gillett Grove and Brooke township had there been no Little Sioux valley, can be only conjectured, but it probably would not have been very different. The boundary has a southwest direction where it strikes the Little Sioux at Gillett Grove and this general direction continues to section 16 of Herdland township. From here westward to Linn Grove its exact course was influenced by the valley. However, the course of this part of the Little Sioux valley was itself probably determined by the position of the ice-front, and had the force of the thrust westward not been largely spent, the river would have been crowded farther over into southern Clay county. Without the valley the ice-front probably would have gone on west across southwestern Herdland and southern Douglas townships.

This westward thrust of the Wisconsin ice seems still more peculiar in view of the fact that the southwest direction which must have prevailed over southeastern Clay and across Buena Vista counties was transverse to the drainage courses of that time, and almost directly up the slope of the great watershed, and that the northwesterly direction which was held at least locally was directly up the valleys. Certainly no favorable topographic configuration is to be found to explain this westward thrust of the Wisconsin ice.

The marginal portion of the Wisconsin drift-region in Buena Vista county and the southeast corner of Clay county is a slightly rolling glacial plain with scattered patches of slightly hummocky topography (Plate XV). These patches consist of single hummocks or kames, of irregular or roughly equidimensional patches, and of elongate areas. Most of the areas cover only a small part of a square mile and none more than a square mile. There appears to be no regular distribution of these patches. Some of them are near the margin, as in section 36, Brooke township, and section 1, Elk township, and in sections 27 and 21, Washington township. Some are several miles back from the boundary as in sections 22, 23 and 10, Washington township, in sections 35, 33 and 1, Scott township, and in the west parts of sections 18 and 19, Lee township. They are most numerous in Washington township north of Storm Lake, and thence isolated patches are present in Scott, Barnes, Lee and Herdland townships. Detailed study of this region probably would show that many of these isolated patches of terminal moraine could be aligned in belts which mark short periods of rest for the ice-margin.

The chief feature of the Wisconsin plain, however, is not the patches of hummocky topography but the large undulations, depressions and elevations, of the ground moraine type. The hills are large, some of them covering a quarter-section, and their slopes are gentle.

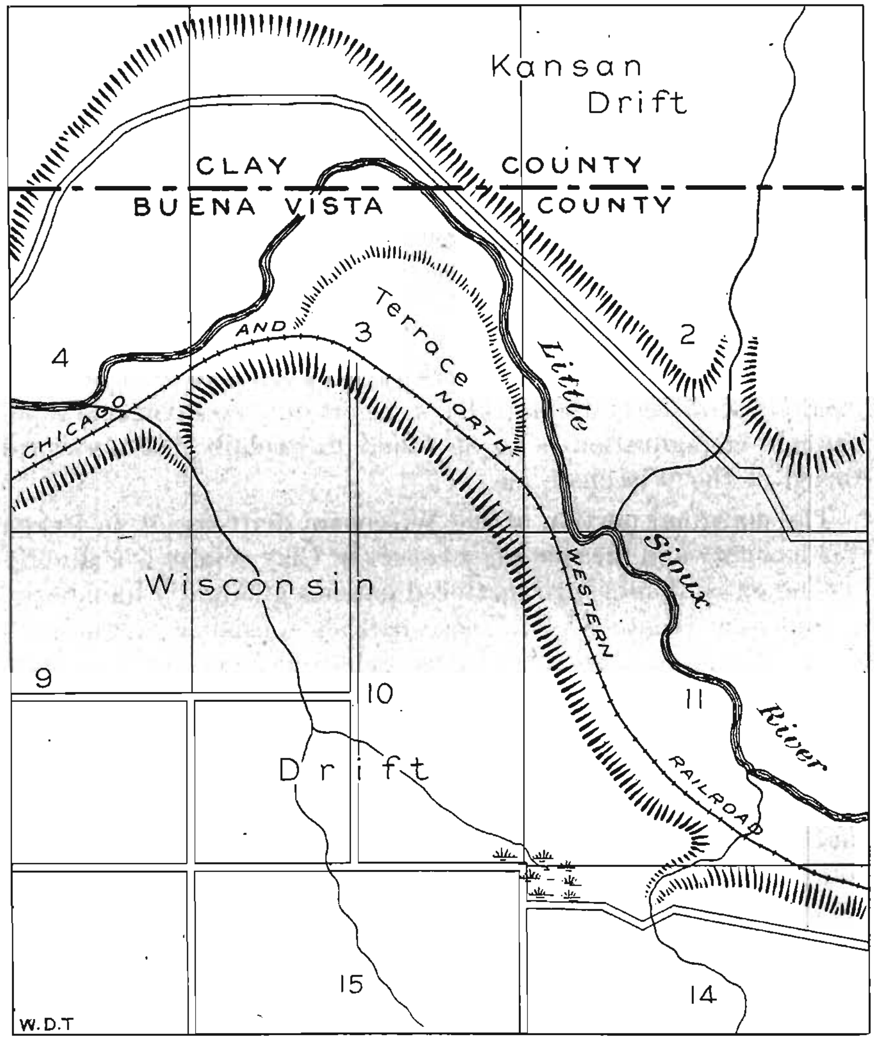


FIG. 29. Sketch map of a part of northern Barnes township, Buena Vista county, showing immature drainage on the Wisconsin drift. The swamp at the northwest corner of section 14 is only a quarter of a mile from the edge of the Little Sioux valley to the northeast, but the drainage goes northwest and travels two miles before it reaches the river.

A good illustration of the recency of the plain and of the independence of the relief features with respect to the drainage courses, is found at the northwest corner of section 14 of Barnes township (figure 29). Here is a swamp about ten acres in extent, on the upland and within one-fourth mile of the edge of the Little Sioux valley to the northeast. It drains, however, to the northwest and its waters reach the river only after a course of two miles.

East of the center line of Buena Vista county the region passes into a slightly rolling to flat glacial plain, and this continues eastward across western Pocahontas county. Shallow depressions occupied by marshes or shallow ponds once dotted this plain, but most of them have been drained by ditching or tiling and now form the richest of agricultural land.

Through sections 7 and 8 of Barnes township, south of Linn Grove, the boundary is about half a mile south of the Little Sioux valley, leaving a narrow strip of the older plain to the south of the valley as in sections 24 and 13 of Brooke township just to the west. Erosion has obscured the evidence in the northern part of section 9, Barnes township, but probably this area was covered by the Wisconsin ice and the margin came to the valley edge at the northwest corner of this section. The margin is the edge of the bluff eastward through Barnes township and the glacial topography extends northward through section 10 into the loop of the river valley in section 3. At Sioux Rapids there is another northward loop of the river and the ice pushed well out into this loop, at least to the north line of section 7, Lee township, and probably to the end of the spur of the upland. To the east the boundary is close to the river bluff through section 8, Lee township, but in the northwest quarter of section 9 it draws away from the bluff, extends northeast across section 4, and crosses the county line at the northwest corner of section 3.

In Herdland township of Clay county the boundary extends north along the west line of section 34 and meets the edge of the valley again in the southwest quarter of section 27. The southeast part of section 33 and the northwest part of section 4 to the south, between the boundary and the valley edge, have an even surface of the type found west of the river. The west parts of sections 27 and 22 are much dissected and the Wisconsin topography has been entirely destroyed, but the presence of Wisconsin drift shows that the ice here pushed up to the edge of the valley. At one place in the west part of section 27, where every trace of Wisconsin topography has been destroyed, a steep ravine slope showed fifteen feet of Wisconsin till above fifty feet of older till, and at several places in the west part of section 22, exposures of twenty feet of Wisconsin till were found. The Wisconsin drift-plain extends westward through section 16 into the loop of the river in western Herdland township, and to the edge of the valley northward through northern Herdland and southeastern Gillett Grove townships to the mouth of Elk creek.

In sections 27 and 22, Herdland township, most of the spurs between the valley-side ravines show narrow shoulder-like areas sixty-five to seventy feet above the river. These are remnants of a narrow bench which once existed along the side of the valley. Farther north the bench is less dissected and broadens out in the west part of section 16, to a width of half a mile, although it is not clearly separated from the plain to the east. Through northern Herdland and southeastern Gillett Grove townships it is narrower. Very little of this bench is level and in places it has a glacial topography. The inner boundary is commonly indefinite, so that the bench area grades into the glacial topography to the east. The surface material is in most places a gravel or bowlder deposit, but locally Wisconsin or older till appears beneath this. Bowlders are common especially on the crest of the front overlooking the river. When the ice had withdrawn slightly from its maximum extent and while there was yet obstructed drainage in the valley at the level of the bench area, gravel material was washed down from the ice-front to the east and spread out in the ponded waters of the valley. With the deeper cutting of the valley this leveled-up area was largely destroyed, but a few benches remain.

The mapping of a boundary so peculiar as the one just traced from Brooke creek to Gillett Grove should be based upon very firm data and such is the character of the data with which we are dealing. They consist first of physiographic evidence and second of stratigraphic and lithologic evidence.

The Wisconsin drift-plain on the south and east of the valley has a distinctly glacial topography, the chief features of which are of the ground moraine type, but which include also small scattered patches of terminal moraine (Plate XV). This glacial topography, so distinctive of the Wisconsin drift-regions, continues up to the very edge of the Little Sioux valley and pushes out into the northward and westward curves of the valley.

On the north and west of the Big Sioux valley in Clay county the region is very different. An even plain extends up to the edge of the valley, where it breaks off abruptly to steep valley sides. Viewed from across the valley the altitude of this crest is remarkably uniform (figure 38, page 315). On the south where the glacial topography extends to the edge of the valley the crest is not so sharp as on the north and the valley slope passes more gradually into the rolling plain of the upland. In some places, as in Herdland township, the altitude of the crest of the northwest bluff, which comes within a quarter to half a mile of the river, is not reached on the southeast of the valley within a distance of three to four miles (figure 30). Back on the plain to the north the surface has only a slight relief, less than that of the Wisconsin drift-plain, but the features of this plain are broad valleys and rounded divides. Many of the slopes are very gentle, so that the surface appears almost flat, but there is some slope, and the drainage of the region is complete. Nearer the larger valleys, such as Willow creek, the relief is greater, and the slopes are steeper, but the features are of the same general type.

The evidence which determines the location of the Wisconsin boundary, however, is not simply physiographic, although this is thoroughly adequate for the conclusion that the Wisconsin ice pushed up to the Little Sioux valley from Gillett Grove to Linn Grove and occupied all the territory to the south and east, but did not at any place cross the Little Sioux valley. One cannot go

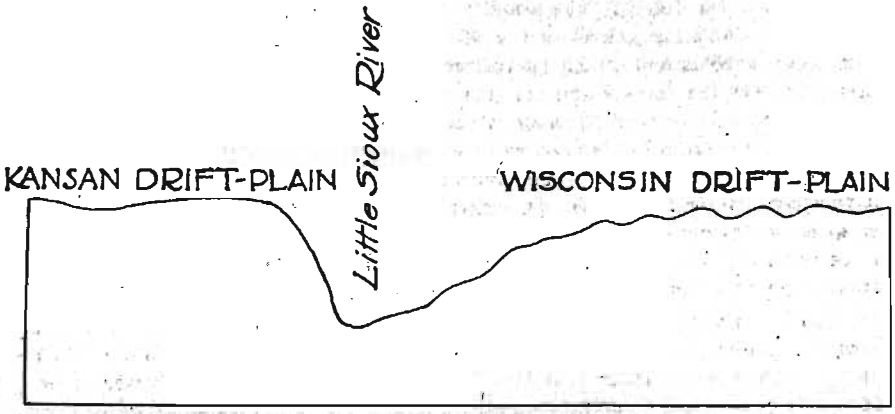


FIG. 30. Profile across the Little Sioux valley in Herdland township, Clay county. The even upland on the left is the Kansan drift-plain. The less abrupt slope on the right with undulating surface is the Wisconsin drift-plain.

far into the Wisconsin area before noting the pebbly, gritty soil and the presence of bowlders on the surface. On the Kansan area, on the other hand, bowlders are seldom seen and the surface is generally covered by a pebbleless, loesslike loam.

The drift into which the Little Sioux valley is cut from Gillett Grove to Linn Grove is Kansan. There are many exposures, natural and artificial, along the steep slopes of the valley and in the lower courses of the tributary ravines. On the north this till continues to the crest of the steep slopes, but in the upper portion of the south slopes of the valley and on the plain beyond one finds exposures of the Wisconsin till.

At the middle of the north line of section 9, Lee township, Buena Vista county, there are some pits in a sand and gravel horizon overlain by Wisconsin till, and underlain by the Kansan till. To the west down the slope toward the valley only the Kansan till appears, while eastward to the upland only Wisconsin till is seen.

East of Sioux Rapids the Chicago and North Western railway leaves the valley and passes eastward up a ravine to the upland. From Sioux Rapids eastward to the center of section 8, Lee township, only the Kansan till is exposed, but east of this, the railway is well up on the valley slope and Wisconsin drift forms the upper part of several of the exposures. A thin, ferruginous, stony horizon at the top of the older till, grayish blue silts, or a fresh sand horizon, separates the two tills in most cases, but locally the Wisconsin till rests directly upon the Kansan.

In the southwest part of Sioux Rapids where the Minneapolis and St. Louis railway crosses the wagon road by a high bridge, blue or brownish yellow till is exposed in the ravine bed, as also to the east along a gully and the railway cut, over a vertical thickness of about seventy feet. The till is typical Kansan and shows in its oxidation several stages intermediate between the blue clay and the yellow. Above the railway cut a grassed slope rises twenty feet to a gravel pit, which exposes about five feet of coarse gravel overlying an equal thickness of coarse sand. The sand becomes finer downward and there is said to be at least six feet of "quicksand" (probably fine sand) below the bottom of the pit. Above the gravel of the pit is a fresh light yellow till which contains a few pebbles and which pulverizes to a fine loesslike material with very little grit. On the face of the pit this till where dry is very hard and owing to horizontal and vertical jointing it breaks out in rectangular blocks. About four feet of this fresh till is exposed and then a grass-covered slope rises twenty feet to the top of the hill. This upper till is not typical Wisconsin, but from its position, its freshness, and its contrast with the Kansan down the slope, it must be the Wisconsin till. Across a ravine to the south is an abandoned pit in the same gravel stratum, which is overlain by the same light yellow till, and gravel appears at several other nearby places at the same altitude.

A short distance to the south, one hundred yards south of the northwest corner of section 18, Lee township. brownish yellow till forms the lower thirty feet of a roadside exposure, and blue till outcrops in a ravine bed lower down, about fifty yards to the northwest. At the top of the till is a six to twelve inch layer of rusty, sandy material, with some rotten bowlders. Then comes a blue-gray loesslike material, three and one-half feet thick, the upper part of which contains small gastropod shells that look like the ordinary loess fossils. The next horizon is more silty, as if deposited in water, and consists of several feet of bluish gray silts. Above these silts is several feet of sandy silt and fine sand which is banded brown and yellow and is followed by a zone of very fine silty sand six to eight feet thick. The total thickness of the loesslike silts and sands is fifteen to eighteen feet. The sand is overlain by a thin horizon of light yellow, sandy Wisconsin till, which farther up the slope grades into typical Wisconsin till.

At the center of the north line of section 13, Barnes township, the Kansan till rises ten feet above the railway and is overlain by a red iron-stained sand which passes into the soil at the top of the cut. A few rods south and ten to fifteen feet higher, on the south side of the wagon road, a cut exposes at the base six to eight feet of fresh sand overlain by fifteen to eighteen feet of Wisconsin till. Where it is dry this is very compact but it does not have the joints that characterize the Kansan. In one place this upper till contains iron tubules and has at the top a zone with many calcareous concretions.

Other Wisconsin drift exposures in the vicinity of Sioux Rapids may be seen at the top of the hill on the road leading south from Sioux Rapids through the southwest quarter of section 7, with the Kansan till exposed in the lower part of the slope to the north; eighty rods east of the southwest corner of section 7, with the older till on the slope to the west; and along the east side of the southeast quarter of section 7.

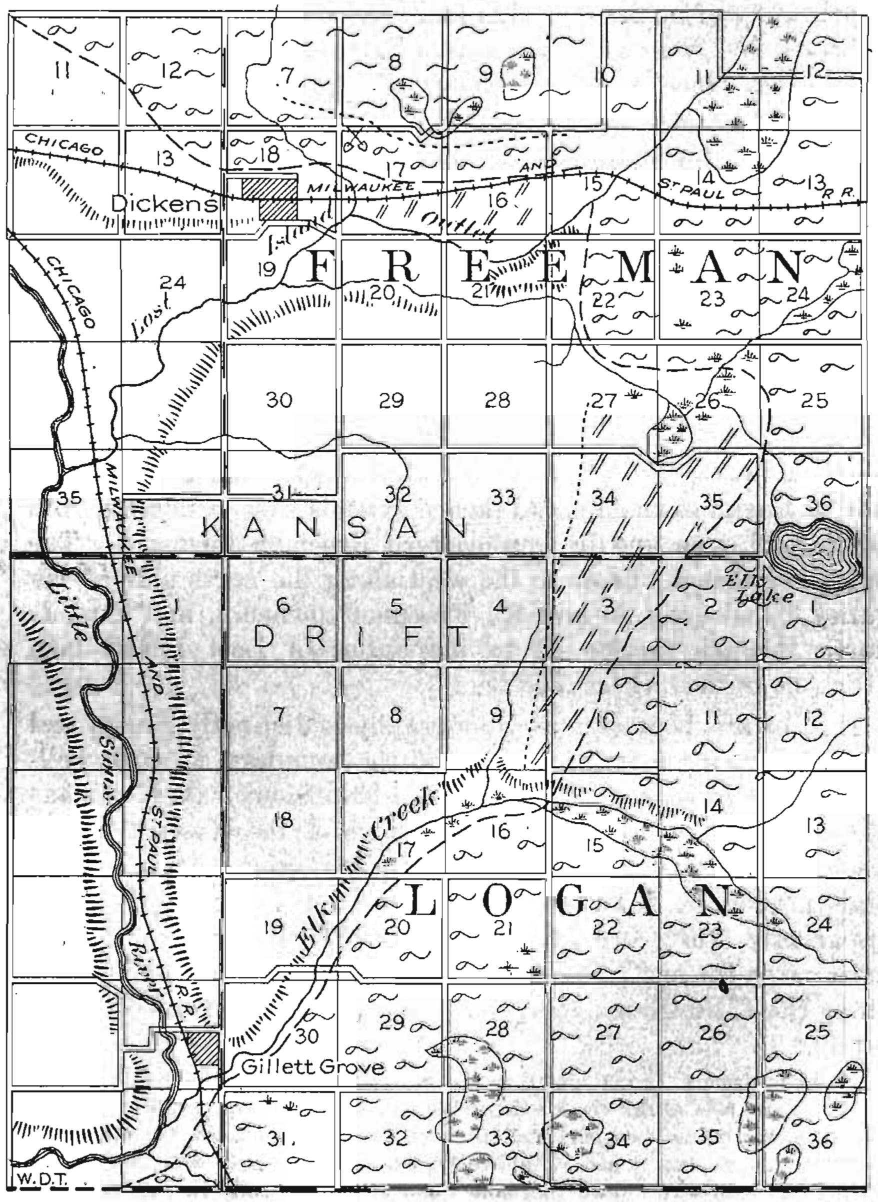
From Gillett Grove to the Dickens Outlet.—Near the township corner south of Gillett Grove, the relief and ruggedness of the Wisconsin topography increases, and in the southwest corner of Logan township the terminal moraine is prominent and extends eastward and northeastward across the township. This is the first large area of terminal moraine found along the Wisconsin boundary in all the course from Des Moines northward.

The southcentral part of Logan township is high, with a rugged topography of hummocky hills and ridges, inclosing depressions occupied by swamps and ponds. Farther eastward this high area gives place to elevated belts of terminal moraine with a north-south trend and separated by belts of lower altitude and less rugged topography. Farther south in Garfield township the moraine is weaker and is broken up into higher and lower belts of ground moraine with the same north-south trend. These extend into northeastern Buena Vista and northwestern Pocahontas counties with some patches of terminal moraine, and there the whole grades into a slightly rolling plain of ground moraine.

At the mouth of Elk creek south of Gillett Grove, the Wisconsin drift boundary leaves the Little Sioux valley and extends northeastward (Plate XVI). It follows Elk creek to the center line of Logan township, and thence extends east of north across northern Logan and in southeastern Freeman township. The boundary thence offsets to the west along the north side of the valley in sections 26 and 27, Freeman township, and extends north through section 22 to the outlet of Lost Island lake (Dickens outlet) (Plate XVI).

East of this boundary the topography is distinctly glacial and in part strongly morainic. West of the boundary a slighty rolling plain stretches westward to the Little Sioux valley. It has the gentle slopes and the broad valleys of the Kansan region west of the Little Sioux in Clay county. Some parts of this plain nearer the Wisconsin drift-border are especially flat, and apparently were affected by the outwash material from the moraine to the east. Near the valleys the relief is greater, and along the Little Sioux there is an area of well dissected topography.

Through western Logan township the edge of the Wisconsin drift-area lies along the east side of Elk creek valley (Plate XVI). The floor of this valley consists of marsh or meadow land and lies about seventy feet below the upland to the west. In sections 16 and 17 this valley floor is half a mile wide, but it narrows to the southwest, down the valley, and at the township line the flat has disappeared. In section 16 the direction of the valley changes to east by southeast, and it extends with a width of a quarter to half a mile, several miles into the area of the Wisconsin drift. The west slope of Elk creek valley along the Wisconsin boundary is steep and rises to a level crest that marks the elevation



Map of parts of Freeman and Logan townships of eastern Clay county, showing features discussed in the text. Curved lines with loops represent morainic Wisconsin drift. Curved lines represent Wisconsin drift. Parallel lines show area affected by outwash from the Wisconsin ice-sheet.

of the Kansan drift-plain to the west. Locally the slope is gullied and ravines head back into the plain. On the east the slope is longer and less steep, and passes more gradually into the glacial topography of the upland, which at a distance of a mile from the valley is somewhat higher than the upland on the west.

A slope rising thirty to forty feet above the region to the west marks the boundary through section 10, Logan township, but it is less prominent to the north in section 2, and is not present in southeast Freeman township; but the area to the east, along the county line, continues higher and slopes down to the west.

West of the boundary in northern Logan and southern Freeman townships there is a poorly developed outwash plain. At the south end where the boundary leaves Elk creek the outwash plain is less than half a mile wide, but it widens northward to one and one-half miles where it is terminated by the low area of sections 26 and 27, Freeman township (Plate XVI). Exposures within this area show only the finer materials such as sand and fine gravel, indicating that only relatively moderate floods came down over the region from the ice-front to the east. The amount of outwash material is probably slight, forming only a veneer, and in places it does not appear to have been sufficient to bury completely the slight relief of the Kansan drift-plain. The western border is an indefinite line where the gravel area grades into the slightly rolling plain to the west. Its course is along the east lines of sections 9 and 4 of Logan township, and through the west part of section 34, Freeman township (Plate XVI).

This is almost the first example of an outwash plain that is found in tracing the Wisconsin drift-margin northward from Des Moines. The boundary follows some drainage line most of the way and the debris was carried away by the streams. For this short distance between Elk creek and the northwestward flowing stream course of section 27, Freeman township, the ice-margin lay on an even plain and conditions were favorable for the accumulation of outwash deposits. Also the thickness of the ice and the length of time its margin remained along the boundary must have been much greater along this strong terminal moraine of eastern Clay county than farther south.

The continuation of the boundary traced northward through Logan and southeastern Freeman townships (page 267) would pass to the east of the low area of section 26, Freeman township, and extend northward through the central parts of sections 23 and 14; and this course would indeed leave all the strongly hummocky topography on the east. But there is to the west of this line an elevated area covering most of section 22 and extending into adjoining sections to the north, east and south, which has a topography consisting of large, rounded elevations of the ground moraine type, upon which appear some small hills of the terminal moraine type. It is separated from the terminal moraine to the east by a low area in the west part of section 23. It is higher than the drift-plain to the west down to which a slope leads in the northwest part of section 22, and must be included with the Wisconsin drift area. Almost surrounded by valleys, some of which are probably of pre-Wisconsin age, this elevation has been especially subjected to erosion, and many of its glacial features have been destroyed. A similar smaller elevation appears in the southwest part of section 14. The boundary mapped in central Freeman township therefore turns westward along the north border of the lowlands of sections 26 and 27 and extends north through the west part of section 22 to the outlet of Lost Island lake (Dickens outlet) near the center of section 15 (Plate XVI). It is a peculiar course, and would be more regular if the outer edge of the outwash plain were taken as the boundary through northern Logan and southern Freeman townships.

The Ruthven Moraine.—The area of pronounced terminal morainic topography which lies east of the Wisconsin boundary from Gillett Grove to central Freeman township continues northward along the county line and in western Palo Alto and Emmet counties, to the Minnesota state line. It is one of the prominent glacial features of northwestern Iowa, probably the most continuous of the morainic belts, and marks the western side of a strong moraine-forming ice-lobe which occupied the Des Moines drainage basin. The moraine has been named the Ruthven moraine from the town of Ruthven which stands on its crest near the west line of Palo Alto county. Its western boundary extends through eastcentral Freeman and Lake townships of Clay county, across the southeast corner of Dickinson county, through western Twelve Mile Lake and Estherville townships of Emmet county, and in southern Superior township in northeastern Dickinson county is terminated by the union of this moraine with another morainic area from the southwest (Plate XV).

The eastern boundary of the Ruthven moraine through northwestern Palo Alto county is at most points about two miles west of the Des Moines river valley, with an intervening belt of ground moraine (Plate XV). In southwestern Emmet county the terminal belt is close to the valley across Twelve Mile Lake township, but is again a mile back from it in southern Estherville township. North of Estherville, the boundary crosses the Des Moines valley and extends north through eastern Emmet township to the state line. From Ruthven north to the county line the moraine is eight to ten miles wide, but through Emmet county the average width is only four to six miles.

The topography of the Ruthven moraine is very rugged, with a relief of fifty to one hundred feet. The hummocks are steep-sided and many of them show bowldery or gravelly material on their summits. The depressions are likewise steep-sided and many of them contain small lakes or swamps which cannot be drained because of the depth of the depressions. Several lakes of some importance are included in the belt, as Elbow and Virgin lakes to the south of Ruthven, Lost Island and Trumbull lakes to the north, and Twelve Mile, Cheever, and Four Mile lakes in western Emmet county.

Southwestern Palo Alto county was not studied in detail by the writer. Professor Macbride mapped it on the Palo Alto county map[30a] as "Morainic Deposits," a division in which he placed all of those parts of Palo Alto and Emmet counties west of the Des Moines river valley. A general survey of the region, however, showed that southern Palo Alto county contains much that should not be classed with the Ruthven moraine. South of Ruthven, in Logan, Silver Lake and Great Oak townships, the moraine appears to separate into a number of belts which extend to the southwest, south and southeast. These are separated by belts of ground moraine, so that the whole forms a succession of terminal and ground moraine areas, or relatively elevated and depressed areas, which have a general trend from north to south. Farther south the terminal belts are weaker, in places mere isolated hummocky patches, and then these fail and the topography grades into the even glacial plain of eastern Buena Vista and of Pocahontas counties. The most prominent of these morainic areas is located along the county line and to the west in Logan and Garfield townships of Clay county (page 267), and south of the county corners in northeastern Buena Vista and northwestern Pocahontas counties. Other terminal moraine belts or areas, separated by ground moraine areas, were seen in Silver Lake, Great Oak, Rush Lake and Ellington townships of southern Palo Alto county. Detailed work in this region probably would show a system of diverging and disappearing moraines which mark the breaking-up of the Ruthven moraine.

A hundred miles to the east there is a similar prominent moraine which extends from north to south in western Worth, Cerro Gordo and Franklin counties. South of these counties this moraine likewise is progressively less prominent and it fails by many miles to attain the southward extent of the Des Moines lobe. These strong moraines of northern Iowa mark the loca-

[30a]Iowa Geol. Survey, Vol. XV, p. 254.

tion of the edges of the ice during much or all the time that the ice-front was advancing southward to Des Moines and retreating again to northern Iowa.

From the Dickens Outlet to the Okoboji Outlet.—The line which marks the extreme western edge of the Des Moines lobe turns westward north of the Dickens outlet in central Freeman township and extends west along the north border of the outlet to Dickens. The course is thence northwest across northeastern Sioux township, north through central Meadow township, and north by northwest through western Milford township of Dickinson county to the outlet of the Okoboji lakes (Okoboji outlet) northeast of the town of Milford (Plate XV and figure 31).

The features of this portion of the boundary are very different from those of southeastern Clay county, different also from those of the boundary through Buena Vista and Sac counties, and therefore the criteria upon which the separation is based are somewhat different from those used farther south. It is one of the most difficult parts of the boundary to trace, and calls for careful observation as well as familiarity with the significant but slight differences that exist.

The course along the north side of the Dickens outlet is marked by an inconspicuous terminal moraine, but northwest of Dickens the Wisconsin drift-region has only scattered patches of slightly hummocky topography. Part of the region to the west of the boundary in northern Clay county is more level than the Wisconsin drift-region, but glacial features are not present. West of the boundary in Milford township there is a narrow flat area which is in places marshy. It was a flat pre-Wisconsin surface, and probably was made more level by the outwash from the Wisconsin ice. It is widest west of the center of the township in sections 17 and 20 (figure 31), and extends southward to the county line as a narrower belt. On the west it merges gradually with the slightly rolling Kansan plain.

The Wisconsin margin reaches the south edge of the Dickens outlet in the southwest part of section 15, Freeman township. North of the outlet a low, ridgelike belt of terminal moraine about half a mile wide extends westward through the northern halves of sections 15, 16, 17 and 18 (Plate XVI). The south base of this ridge, which extends along the center lines of these sections, was mapped as the Wisconsin boundary. Between this boundary and the valley of

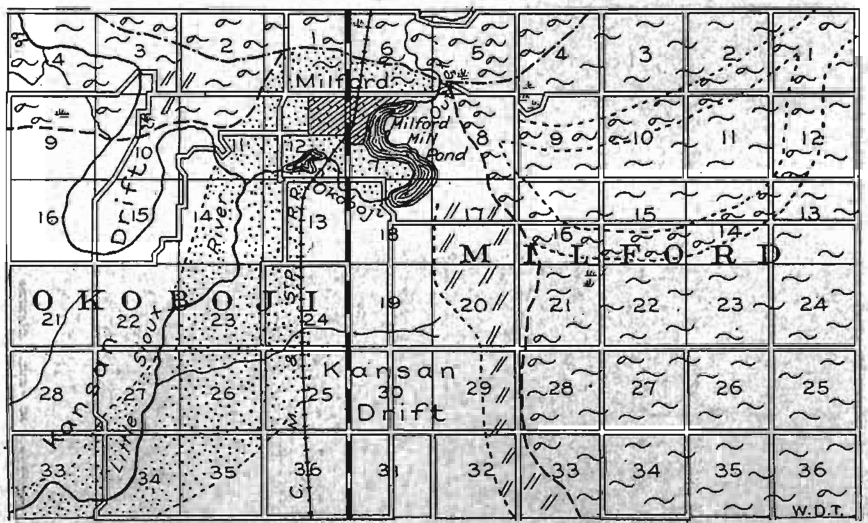


FIG. 31. Map of the region around Milford, Dickinson county, showing features discussed in the text. Curved lines with loops represent morainic Wisconsin drift. Curved lines represent Wisconsin drift. Parallel lines show area affected by outwash from the Wisconsin ice-sheet. The area shaded with dots is the Milford gravel flat.

the outlet, there is a narrow belt a quarter to half a mile wide, which has a slope toward the outlet, and is in part dissected and in part, as in the southeast quarter of section 16, is so level as to be marshy. This strip apparently was not covered by the Wisconsin ice, although it was modified by the outwash material. On the north, the morainic ridge has an indefinite border and grades into the ground moraine which, with a relief of ten to twenty feet and numerous swamp areas, covers the northern part of Freeman township (figure 32).

This moraine north of the outlet is quite insignificant in comparison with that of southeastern Clay county. It is, however, characteristically morainic, with hummocks of small relief, and at the northwest corner of section 17 there is a patch of definite terminal morainic topography with several gravel kames (Plate XVI). Just northwest of Dickens, in the northwest quarter of section 18, there is a good example of glacial topography of very slight relief. The surface is indeed quite level and yet one finds on close study those very significant little undrained depressions, here not deep enough to hold ponds but clearly marked by slightly marshy spots, and low mounds fortuitously placed with respect to the drainage courses. Bowlders were formerly rather abundant on the surface and several hundred are now piled along the fences in the fields just north of Dickens. On the south line of the southwest quarter of section 17, the roadside gutter on the west slope of the creek valley shows the older till overlain by three to four feet of Wisconsin till. The two tills are here very much alike, the chief difference being the more sandy nature of the Wisconsin which allows it to crumble and break with an uneven, granular surface, while the larger clay content of the older till makes it more plastic and causes it to break with a smooth surface.

FIG. 32. Wisconsin ground moraine of sections 8 and 9, Freeman township, Clay county. (Photo by Lees.)

At Dickens the drift-boundary turns northwest and extends along the southwest base of a low, broad ridge diagonally across the northeast quarter of section 13, the southwest quarter of section 12, the north half of section 11, and section 3, Sioux township, at a distance of one mile to one and one-half miles from the edge of the Little Sioux valley. To the northeast of this boundary there is an area of slightly rolling glacial topography with a few undrained depressions. To the southwest the region has a similar relief, but the distinctive glacial features are not found. Some parts just outside the boundary, especially in sections 11 and 10, are almost flat and probably were leveled up by outwash material.

In the north part of section 3, Sioux township, an interstream elevation begins and continuous northward into Meadow township, through the west half of section 34, and the east halves of sections 28 and 21 to the town of Langdon. In the west half of section 34 and the southeast quarter of section 28 the topography of this elevation is slightly hummocky. Farther north the hummocks are absent, but the topography is glacial with numerous ponds and marshes. The Wisconsin drift-boundary swings around the south end of this interstream elevation and extends northward along its west slope (Plate XV). To the west of the boundary the effect of the outwash is seen at several places in sections 28 and 21, where flat, marshy areas exist.

East of this boundary along the center line of Meadow township the topography is glacial and there exist other north-south interstream areas, like the one described above. One of these, with good terminal moraine topography, extends through the central part of section 27 and the east halves of sections 22, 15 and 10, and another through the east row of sections of the township. West of the boundary the surface is quite level but glacial features are absent. In the eastern part of the township gravel and stones are common at the surface, especially on the hills, but in the western part the roads are free from gritty material of any sort.

Northwest of the center of Meadow township there is a large marshy area. Glacial topography extends up to the east edge of the marsh, and within it, as in the northeast quarter of section 9, faint indications of glacial topography appear. The boundary, as mapped, swings to the east, through sections 15 and 10, along the east edge of the marsh, but the ice-edge probably formed, at least temporarily, a more direct line across the east parts of sections 16, 9 and 4. This marsh area lies just outside the Wisconsin drift-boundary and may have been leveled up slightly by outwash materials. Although it is marshy and almost flat, it is quite different from the enclosed glacial depressions in the Wisconsin drift.

Extending in an east-west direction through the north row of sections of Meadow township is a southward-facing front fifty to sixty feet high. It is a pre-Wisconsin feature that continues east through the northwest corner of Lake township and into southeastern Dickinson county. To the southwest this front lengthens into a long southward slope which crosses western Meadow and eastern Summit townships. The Wisconsin boundary strikes this front in the west part of section 3, and rising to the higher level to the north, leaves the county at the northeast corner of section 4. Section 3 is much dissected and most of its glacial features have been destroyed, but at the northwest corner a swamp appears and a glacial plain with bowlders on the surface lies just to the north over the county line.

In Milford township, Dickinson county, the boundary extends northwest diagonally across section 33, north along the west line of section 28, makes a slight reëntrant in the northwest quarter of section 21 and the southwest quarter of section 16, and thence extends northwest by north through the northeast quarter of section 17 and the central part of section 8 to the Okoboji outlet in the southeast quarter of section 6 (figure 31). The marginal topography of the Wisconsin drift of this township is in general, a slightly rolling ground moraine with a few patches of terminal moraine topography. In section 33 a low slope with a few small hummocks and granite bowlders marks the boundary, and in the northwest quarter of section 28 and the southwest quarter of section 21, near the margin, there are a few gravel kames. In the west part of section 16 and again in the east part of section 8 a small ridge area of terminal moraine approaches the boundary from the east and swings northward to unite with it (figure 31). The north part of section 8 is high and the topography is of the terminal moraine type.

The Terminal Moraine around Okoboji Lakes.—In the northwest corner of Milford township, the boundary abuts against an area which has a strong terminal morainic topography (figure 31). This area extends north to the Okoboji lakes, and continues, as a belt three to five miles wide, to the northeast and to the northwest. It is a belt of strong terminal moraine which loops the south end of the Okoboji lakes, and has in northwestern Milford township its most southern extension. To the northeast its outer edge crosses southeastern Center Grove and northwestern Richland townships, and in southern Superior township this morainic area spreads eastward so as to unite with the Ruthven moraine (Plate XV). A strong terminal moraine exists to the west and north of this boundary and covers most of the area to East Okoboji and Spirit lakes and to the Minnesota state line. Southeast of the boundary, southeastern Dickinson and northeastern Clay counties have in general a ground moraine topography, but with patches or belts of faint terminal moraine.

To the northwest, the outer edge of the strongly morainic area extends west across the north parts of sections 1, 2 and 3 of Okoboji township and then north along the Little Sioux valley through southern Lakeville township. From this boundary north and east to the lakes a strong terminal moraine topography is present as on the east side of the lakes (figure 33). In fact there exists in this area around the lakes probably the most pronounced morainic topography in the state. A belting of features somewhat parallel to the boundary noted above was observed in Diamond Lake, Spirit Lake, and Center Grove townships, and it appears that a lobe of ice (Okoboji lobe) occupied the site of the lakes and built this strong morainic topography around them. The solution of these interesting problems could not be entered into, but they will involve an exact mapping of this region around the lakes as well as a study of the district just to the north in Minnesota.

Great floods of water, from the ice-edge which built this strong moraine, flowed southward across sections 6 and 1 north of Milford, and later by the Okoboji outlet and by low courses leading southward from Brown and Emerson bays at the south end of West Okoboji lake. These waters built up the great gravel flat (Milford flat) which begins north of Milford and continues south and southwest to the Little Sioux river valley down which it con-

FIG. 33. Morainic topography at the north end of West Okoboji lake, Dickinson county. This district contains probably the most pronounced morainic topography in the state. (Photo by Ewers.)

tinues as a great gravel terrace across the southern part of the county and south to Spencer. The extent of this flat near Milford is shown in figure 31, and a view of the terrace which forms a distinct bench, high above the river but below the level of the upland, is given in figure 34. These gravels have been extensively worked just southwest of Milford for railway ballast.

The area of this aggraded flat, from its head north of Milford south to the county line, was at the time of its formation about eleven square miles. The thickness of the gravel varied greatly, but averaged about twenty feet, which over the area given above, would make a bulk of more than six billion cubic feet (one-twenty-fourth of a cubic mile). Southward in Clay county there is an area of more than fifty square miles over which the gravel had an average thickness of probably ten feet, making about fourteen billion cubic feet more. The total was about twenty billion cubic feet or about one-seventh of a cubic mile, and the major part of it entered the Little Sioux valley from the Okoboji outlet. This gives some idea of the great quantity of water and debris which was discharged at this place.

FIG. 34. The Little Sioux valley, looking west in the northwest quarter of section 13, Okoboji township, Dickinson county. The view is from the edge of the Milford terrace and shows the terrace on the west side of the river forming a distinct bench seventy feet above the river and twenty-five to thirty feet below the upland. (Macbride, Iowa Geological Survey, volume X, p. 199.)

From the Okoboji Outlet to the Ocheyedan River.—West of the Okoboji outlet the boundary of the Wisconsin drift extends westward across the north parts of Okoboji and Westport townships and along the south line of Allison township of Osceola county to the Ocheyedan river (Plate XV). In northwestern Okoboji township there is terminal moraine topography just north of the boundary, but farther west there is a belt a mile to two miles wide south of the terminal moraine belt which shows faint glacial characters. This is included in the Wisconsin drift. In Allison township, the marginal part of the Wisconsin drift is rougher than through western Dickinson county and in places there is a ridge just inside the boundary. In southeastern Ocheyedan township the edge of the Ocheyedan river flat is the boundary for several miles. For this distance the ice-sheet pushed down to the valley but did not close it. The ice pushed farther southward along the Ocheyedan valley than it would had there been no valley, so that where the ice-margin drew away from the valley on the east it had a course north of east for one and one-half miles until it reached the upland and there took the direction, a little south of east, which it held eastward to Little Sioux river.

Along the Wisconsin boundary from Little Sioux river to the Ocheyedan there is very little outwash material, although the ice-margin lay for most of this distance on a slightly rolling plain, under favorable conditions for the accumulation of debris. In western Okoboji and eastern Westport townships the area just south of the boundary for about a mile is almost flat, and similar smaller patches appear farther west in Allison township. These areas are aggraded only sufficiently to fill the shallow valleys that existed previously. Elsewhere in most places along the boundary a low slope continues southward a short distance and the surface shows the effect of outwash to the first small valley that leads either east or west to the southward flowing creeks. The way in which the outwash features terminate near the heads of even the smallest of these valleys shows that the quantity of water flowing from the ice-front at any one point was relatively small.

Where Stony creek leaves the Wisconsin boundary in northwestern Westport township its valley flat is more than a mile wide, but within two miles it narrows to about half a mile. Gravel underlies the flat, but its thickness is probably slight for the creek occupies one of the broad shallow valleys of the Kansan plain, and part of the gravel of the valley may be of pre-Wisconsin age. The Ocheyedan river valley flat in southwestern Osceola county is a mile to a mile and a half wide and is underlain with gravel and siltlike clay. Most of the flat is bottom land which is high enough to be cultivated and which slopes toward the river without terrace front.

The region to the south of the Wisconsin boundary in southwestern Dickinson and southeastern Osceola counties is slightly rolling, with some areas that are almost flat. The more level areas, aside from those leveled by outwash along the Wisconsin margin, are situated midway between the chief drainage lines and have a relief of only ten to fifteen feet. The relief is greater nearer to the larger creeks. The slopes of this region are long and gentle, and many parts that appear to be almost flat are found, on closer study, to have a slight slope toward some shallow drainage channel. There are no ponds like those in the Wisconsin drift area to the north, and no waste land in undrained depressions; but along some of the shallow drainage courses the surface is so level that slough grass meadows are formed. This is a surface distinctly different from that to the north and nowhere shows the distinctive features of glacial topography. The surface soil is a pebbleless loam which passes downward into leached loess. The soil and loess have a combined thickness of two to three feet. In the more level parts there are few exposures of the till, but in the more broken portions along the large valleys many exposures of the buff to brownish yellow till may be found.

From the Okoboji outlet westward to the center line of Okoboji township the location of the boundary is indefinite. The strong terminal moraine area extends southward to the centers of section 6, Milford township, and section 1, Okoboji township, and covers part of the north halves of sections 2 and 3 (figure 31). South of the center lines of sections 6 and 1 there is a narrow belt, thirty to forty rods wide, that has in part glacial features and in part features of the outwash area to the south. It is a sort of transition belt that apparently was covered by the Wisconsin ice, and later was modified by outwash material. In the east part of section 2 this belt is wider and shows several isolated glacial hills twenty to forty rods south of the center line of the section. In the west part of section 2 it is narrow again and so continues into section 3 just north of the center line. The southwest quarter of section 2, the southeast quarter of section 3 and most of the northeast quarter of section 10 have a slightly rolling or flat surface that also was modified by outwash. The north half of section 11 is a slightly elevated broad ridge without distinct glacial features, but bowlders were seen piled along the fences and lying in the fields.

Just north of the center of section 10, south of the farm buildings of Frank Hunt, there are a small pond and two small mounds. They are located on the crest of the spur of upland that projects southward into the loop of the Little Sioux and are not fifty yards from the valley slope either west or east (figure 31). Other small relief features in the field south of the pond have a glacial aspect, and west of the river positive glacial features continue as far south as this point. We therefore conclude that the Wisconsin ice covered the questionable areas described above, as far south as the center of section 10, and that east of here, the margin probably lay along the north edge of the Little Sioux valley as far as the center of section 11. From here the boundary extends north and east along the edge of the Milford gravel plain to the Okoboji outlet in section 6 of Milford township (figure 31).

West of the Little Sioux river a terminal moraine area, with swamps and gravelly kames, covers the north half of section 9. Bowlders appear at the surface, the soil is gravelly, and Wisconsin drift is exposed in several of the roadcuts on the north line of the section. This morainic area extends northwestward over the southwest quarter of section 4, the north part of section 8, and sections 5 and 6 of Okoboji township, and sections 32 and 31 of Lakeville township. Near the township corner the area divides. One branch extends northwest across the northeast quarter of section 36 and the south part of section 25 and dies out beyond the central part of section 26 of Excelsior township, and the other branch extends westward along the south line of Excelsior township. The latter belt is three-fourths to one mile wide and forms a low ridgelike area of moderately rolling topography with many slightly hummocky areas and undrained depressions containing swamps. The crest lies along, or just north of the township line, and the south border, which generally is an indefinite line, lies a quarter of a mile to half a mile to the south. The north border, likewise indefinite, lies about half a mile north of the township line, and north of this is a region of moderately rolling ground moraine with a relief of thirty to fifty feet.

West of the Little Sioux valley the Wisconsin boundary is formed by the south edge of the terminal area across the central parts of sections 9 and 8, Okoboji township. In section 9 a southward facing slope twenty to thirty feet high extends down to the plain to the south. At the west line of section 8, the edge of the terminal moraine belt extends northwestward, but the Wisconsin drift-boundary, that is the southern boundary of the area having glacial topography, turns south of west and continues across the central part of section 7 (Plate XV). In Westport township the boundary takes a course a little north of west through the southcentral part of section 12, the northcentral part of section 11, the north part of section 10 and along the north lines of sections 9 and 8 to the edge of the flat of Stony creek, which it follows across the southwest quarter of section 5 and the central part of section 6 to the county line. An area in the south parts of sections 5 and 4, of a rather questionable nature, is here included in the Wisconsin drift area. In section 7 of Okoboji township and two to three miles to the west in Westport township the boundary is marked by a low southward facing front which gives it a rather definite location. West of the center of the latter township the boundary is not definite.

Between the boundary and the belt of terminal moraine topography along the township line there is an area of glacial topography of the ground moraine type or with only occasional isolated hummocks. In part, it merges gradually into the terminal moraine topography to the north, and in part, it is definitely separated by a low southward facing front or a distinct change in the topography. On the east line of Westport township this belt has a width of more than a mile. It narrows towards the west and terminates in section 5.

In the southwest corner of Excelsior township there are a number of large swampy areas, with associated hummocky topography, which occupy depressions thirty to forty feet below the general level of the region. They occur along the outlet of Stony lake in sections 32 and 29, cover most of section 31, extend southward over the township line into the northwest quarter of section 6 of Westport township, and westward across the county line to include the east half of section 36 of Allison township.

The Wisconsin boundary crosses the east line of Osceola county about half a mile south of the northeast corner of Harrison township and continues its direction of north of west to Ocheyedan river. It extends along the north side of a creek valley through sections 1 and 2 of Harrison township, and thence passes through the south part of section 34 and the central part of section 33, Allison township. Section 32 is considerably eroded and the features are not clear, but the north part appears to be glacial, and the north part of section 31 has a slightly hummocky topography. The boundary is therefore mapped as changing its direction at the northwest corner of section 33 to extend south of west through the north part of section 32 to the edge of the Ocheyedan flat near the center of section 31 (Plate XV). This change of direction to south of west is due to the influence of the Ocheyedan valley upon the ice-margin.

The marginal part of the Wisconsin drift-area through southern Allison township is more rugged than through western Dickinson county. A ridge lies just inside the boundary in section 35, and in general the marginal portion slopes southward toward the boundary. The topography is moderately rolling and is generally of the ground moraine type, with a relief of twenty to forty feet. Slightly hummocky patches appear along the margin in the southeast quarter of section 35, the northeast quarter of section 33, the north part of section 31, and in the north part of section 36 and the south part of section 25 of Ocheyedan township.

The south and west parts of Allison township and the country west to the Ocheyedan valley have a topography of considerable relief, in which the larger features are of the ground moraine type but many small patches of slightly hummocky terminal moraine are included. These latter appear particularly along the depression in which Chain lakes lie, in sections 14, 23 and 26, and in the north parts of sections 28 and 29. The creek in the west part of the township has a valley one and one-half to two miles wide, and in section 20 its bed is eighty to one hundred feet below the divide to the east. But even along this valley most of the relief is constructional or is due to pre-Wisconsin erosion. Kamelike hills appear in the south part of section 30 and in the north part of section 31 along the creek valley.

From the Ocheyedan River to the State Line.—In crossing the Ocheyedan river valley the Wisconsin boundary offsets about two miles to the north and then the course is west across south-central Ocheyedan township, northwest across the northeast part of East Holman township, and north through the west part of Wilson township to the Minnesota state line near the town of Bigelow (Plate XV). For most of this distance, a low ridge area, one-half to one mile wide and with a moderately rolling or slightly hummocky topography, lies along the margin with the base of the outer slope forming the Wisconsin drift-boundary. The ridge itself is not very prominent, but when its significance is appreciated its course may be readily traced. Even where the ridge is wanting, the contrast of the topography to the northeast and to the southwest serves to locate the boundary.

Southwest of the Wisconsin boundary is the slightly rolling Kansan drift-plain. From the crest of the Wisconsin marginal ridge in southern Wilson and northern East Holman townships an excellent view may be had, showing the contrast between the Wisconsin and the Kansan drift topographies. To the east is the glacial area with its slightly hummocky hills and swampy depressions. The chief features of this region are elongated in a direction parallel to the Wisconsin drift-boundary. To the west, broad valleys with smooth slopes lead to the southwest. The courses of these valleys are direct, and one may look down them for miles. In the region to the east a pebbly, gravelly soil is found, and bowlders lie on the surface, while over the Kansan region the soil is pebbleless and no bowlders appear. The pebbleless soil is derived from a thin mantle of loess which overlies the Kansan drift.

Outwash material is absent from this portion of the boundary, just as was noted to be the case east of Ocheyedan river. At a few places, as in sections 21 and 20 of Ocheyedan township and in sections 29 and 20 of Wilson township, a gentle slope leads away from the boundary for a short distance, but commonly there is no evidence of outwash. For three miles in the east part of East Holman township and the west part of Ocheyedan township the ice-margin lay along the slope of the Little Ocheyedan valley, and the waters discharged directly into this valley. Similar conditions existed for two miles south of the state line where the ice-margin lay along the upper course of Otter creek. Neither of these valleys contains any very large gravel deposit. A long slope, cut by broad valleys, stretches to the southwest from the drift-boundary in northeastern East Holman township, and it seems that here the conditions should have been especially good for the accumulation of gravel in the valleys leading to the southwest and yet in these valleys and along the boundary there is no evidence of outwash material. Even the most insignificant valley was not obliterated and gentle slopes may lead directly toward the Wisconsin drift area to some small ravine that follows the drift boundary.

Great quantities of gravel exist to the southwest in the west part of the township, but on lithological and stratigraphical evidence these deposits, though close to the Wisconsin margin, are to be correlated with the gravels at Sheldon and elsewhere on the Kansan plain to the southwest, and are apparently not of Wisconsin age. The evidence as to the age of these extra-Wisconsin gravels will be considered at another place (pages 385 to 392), but even if the gravels at Sibley were the only deposits of this type, it would be hard to explain how they were derived from the ice-margin only three to four miles to the northeast, while the small valleys down which the material must have come, have no gravel deposits.

The general lack of outwash material along the Wisconsin boundary may mean that the marginal part of the ice was thin and that it melted slowly. The lack of outwash material would also indicate that the ice stood for a relatively short time at the line of maximum advance, an idea that is borne out by the slight development of terminal moraine along much of the boundary. The larger valleys however, such as those of Dickens outlet, Okoboji outlet, the Little Sioux, Stony creek and Ocheyedan river, carried great floods and extensive gravel deposits were put down. But even among these, that in the Okoboji outlet—Little Sioux course is the only great deposit. It seems, therefore, that the waters had collected into a few rather large streams either upon, within or beneath the ice before they reached the margin. These large streams generally came out in pre-Wisconsin valleys, and in some cases apparently had followed them for great distances beneath the ice.

If the margin is traced from the south, the first indication of the Wisconsin drift-area on the west side of the Ocheyedan valley is a spur, with rounded glacial hills and a bowldery surface, which projects slightly into the Ocheyedan flat in the southwest corner of section 23, Ocheyedan township. North of the center line of section 22, there is a low ridge fifteen to twenty feet above the region to the north and south. It extends south of west across the central part of section 21 and just south of the center of section 20. This ridge has a faint terminal moraine topography with several kamelike hills in section 21. The south base of the ridge, which extends forty to sixty rods north of the south lines of sections 22 and 21 and near the south line of section 20, is the Wisconsin drift-boundary. An exposure on the north line of section 28, less than half a mile south of the boundary showed beneath one and one-half feet of black soil a foot and a half of calcareous loess with concretions.

On the west line of section 20, the ridge is cut across by a creek valley from the north and in section 19 it is represented by a high rolling area between two valleys. This area continues northwest and broadens out into a high area of rolling glacial hills in sections 13 and 14 of East Holman township south of

Allendorf. The boundary is along the south base of this elevated area, along the north bank of the Little Ocheyedan valley through sections 19 and 24 and north of this valley through the south part of section 14.

The elevated area south of Allendorf is again broken in the west part of section 14 by the valley of the Little Ocheyedan, but it is continued in the northeast quarter of section 15 and the southeast quarter of section 10, covers most of section 10, and then assuming more ridgelike proportions, it extends west of north through the central part of section 4, and through the west part of section 33, the east part of section 29, and the south part of section 20 of Wilson township. This ridge is about half a mile wide from base to base, has a distinct slope in either direction from a rather narrow crest, and has in most places a slightly hummocky topography. The outer base of this ridge is the Wisconsin boundary. North of the center of section 20, Wilson township, the ridge spreads out eastward and unites with another elevated area, but the west slope retains its distinct features northward to the state line. The drift boundary is along the east slope of Otter creek valley through sections 17 and 18 and crosses the state line just west of the northeast corner of section 8 (Plate XV).

About sixty rods north of the southeast corner of section 22, Ocheyedan township, the road crosses the valley of a small stream that is flowing eastward along the Wisconsin drift-boundary. The road-cut in the south slope of the valley exposes brownish yellow Kansan till with concretions. The road-cut in the north slope exposes Wisconsin drift. It is in part a mass of pebbles and bowlders in a clay matrix, and in part a loose, yellow-gray, sandy till with many pebbles and bowlders. The topography to the north of this valley is typically glacial, that to the south is erosional, furnishing an excellent example of the contrast of the Wisconsin and Kansan drift topographies. Where the boundary crosses the township line on the west of section 19, it is following the Little Ocheyedan river valley. The north slope shows Wisconsin till and the south slope shows the older till. Wisconsin till appears in a road-cut a few rods east of the southwest corner of section 13, East Holman township, while just south of the same corner, the older till is exposed. About sixty rods north of the southeast corner of section 15 the road crosses a small valley which is parallel to the drift-boundary and here again Wisconsin till is present on the north slope of the valley and Kansan till is present on the south slope.

The Wisconsin Drift-Region in Northeastern Osceola County.—A mile to a mile and a half to the northeast of the marginal ridge noted above, and concentric with it, is another narrow ridge less well developed, but still traceable from Ocheyedan river to the state line. In Ocheyedan township it passes through the centers of sections 16 and 17 and the northeast quarter of section 18 and is separated from the ridge to the south by a low belt along the south line of these sections. In the southwest quarter of section 7, it unites with another ridge that extends across the southeast quarter of section 7 and the south part of section 8, and thence it continues northwest. It is crossed by the Chicago, Rock Island and Pacific railway at the east line of East Holman township, one mile east of Allendorf, and stretches across the southwest quarter of section 1 and the central part of section 2. A lower, less rough area at Allendorf and to the northwest, which is in part followed by creeks, separates it from the marginal ridge to the southwest. In Wilson township the inner ridge passes diagonally across section 34 and north through the east part of section 28 with a low, swampy belt to the west, and in section 21 merges with the marginal ridge to the west. The merged belt then continues northward beyond the state line. Its topography is a little rougher and its altitude a little greater than in the region just to the east.

Several other ridges or belts of hummocky topography concentric with these and extending for various distances are present to the northeast, in eastern Wilson and western Horton townships. There is a morainic belt or ridge along the east side of the Ocheyedan valley which extends across western Horton township, and terminates in an area of kames in sections 5 and 4 of northwestern Ocheyedan township. Other areas of hummocks or kames are present at a number of places in southern Horton and northern Ocheyedan townships. In the southwest quarter of section 12, Ocheyedan township, a large kame (Ocheyedan mound) rises distinctly above its surroundings and is a prominent feature, visible for many miles around (figure 35). It is elliptical in plan, as it is composed of two hills, it covers an area of almost forty acres and rises about 150 feet above the river two miles to the southwest. Two openings, one at the top and one on the north slope, show sand and gravel.

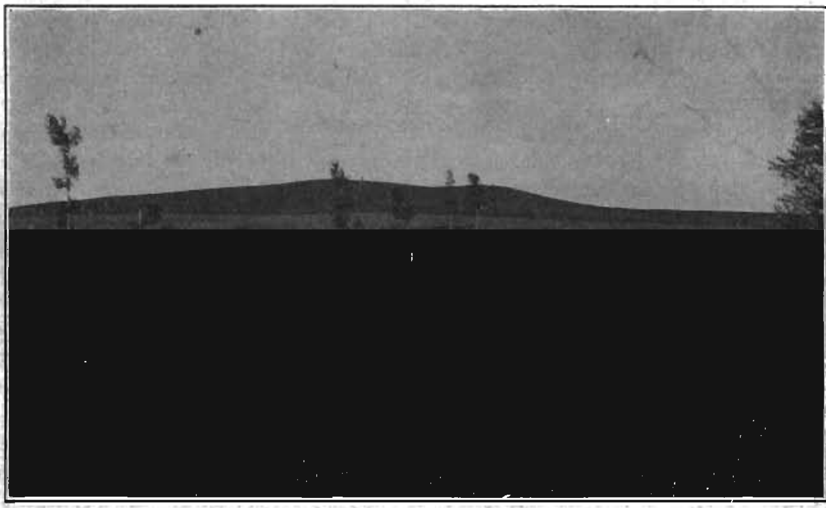


FIG. 35. Ocheyedan Mound, seen from the southwest. This hill is a Wisconsin gravel kame located in the southwest quarter of section 12, Ocheyedan township, Osceola county. It rises distinctly above its surroundings and is a prominent feature, visible for many miles around. (Macbride, Iowa Geological Survey, volume X, p. 195.)

Northern and eastern Horton township, and the southwest half of Fairview township have a ground moraine topography with a few patches of weak terminal moraine and this type continues southeastward over northern Allison township and into Excelsior township of Dickinson county.

Northeast of this ground moraine area is another more rugged terminal moraine area which covers northern Fairview, southwestern Silver Lake and northern Excelsior townships and should connect either eastward across northeastern Excelsior township to the moraine along and east of Little Sioux river in Lakeville township (page 276), or southeastward with the terminal moraine of southeastern Excelsior, southwestern Lakeville and northern Okoboji townships (page 280). Through Fairview township the southern boundary of this more rugged area is along a divide. To the south, the slope is very gentle across the slightly rolling glacial plain. The more rugged area to the north has a lower average altitude but the relief is greater, being thirty to fifty feet. Although it represents a terminal moraine belt it has not the distinctive terminal moraine topography found around the lakes of Dickinson county. Farther east in northern Excelsior township the boundary is less definite. A northeast boundary for this belt was not traced. It appears to pass gradually into a rolling ground moraine in northeastern Fairview and northern Silver Lake townships.

The Boundary North of the State Line.—The Wisconsin boundary was traced north of the state line into Minnesota a

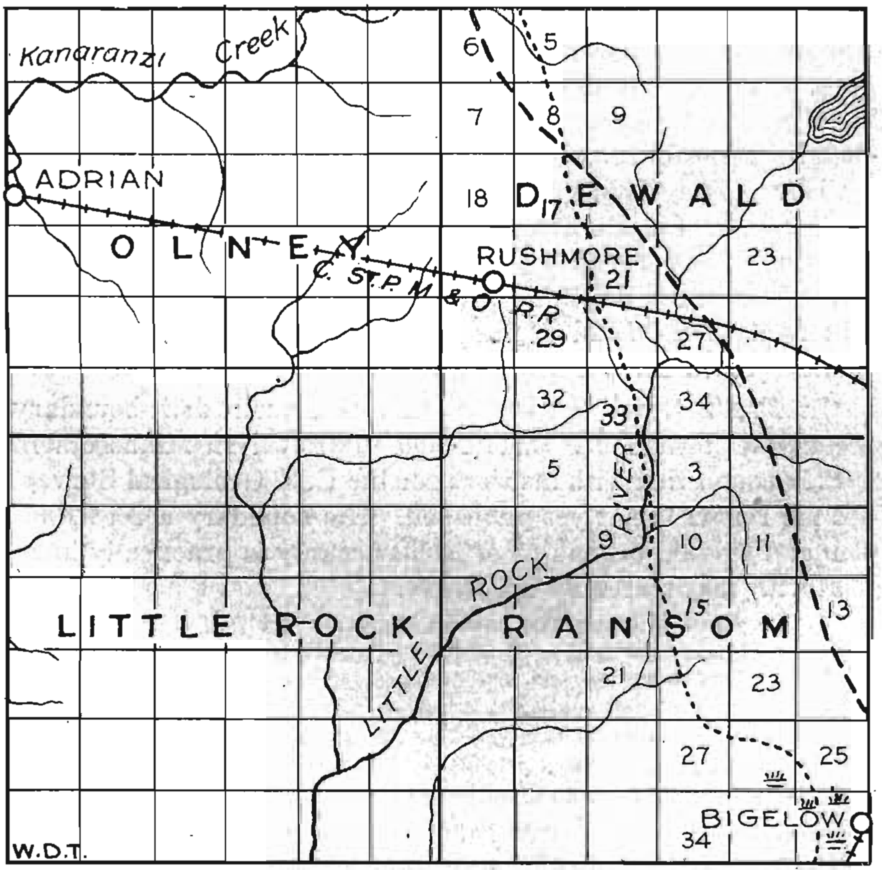


FIG. 36. Map of part of southern Nobles county, Minnesota. The heavy broken line shows the west boundary of the "Terminal Moraine" as mapped by Upham in The Geological and Natural History Survey of Minnesota, volume 1, Plate 21. The dotted line shows the course of the Wisconsin drift boundary as mapped by the writer.

distance of ten to twelve miles, across Ransom and Dewald townships of Nobles county (figure 36), and in this distance it continues in the general direction west of north.

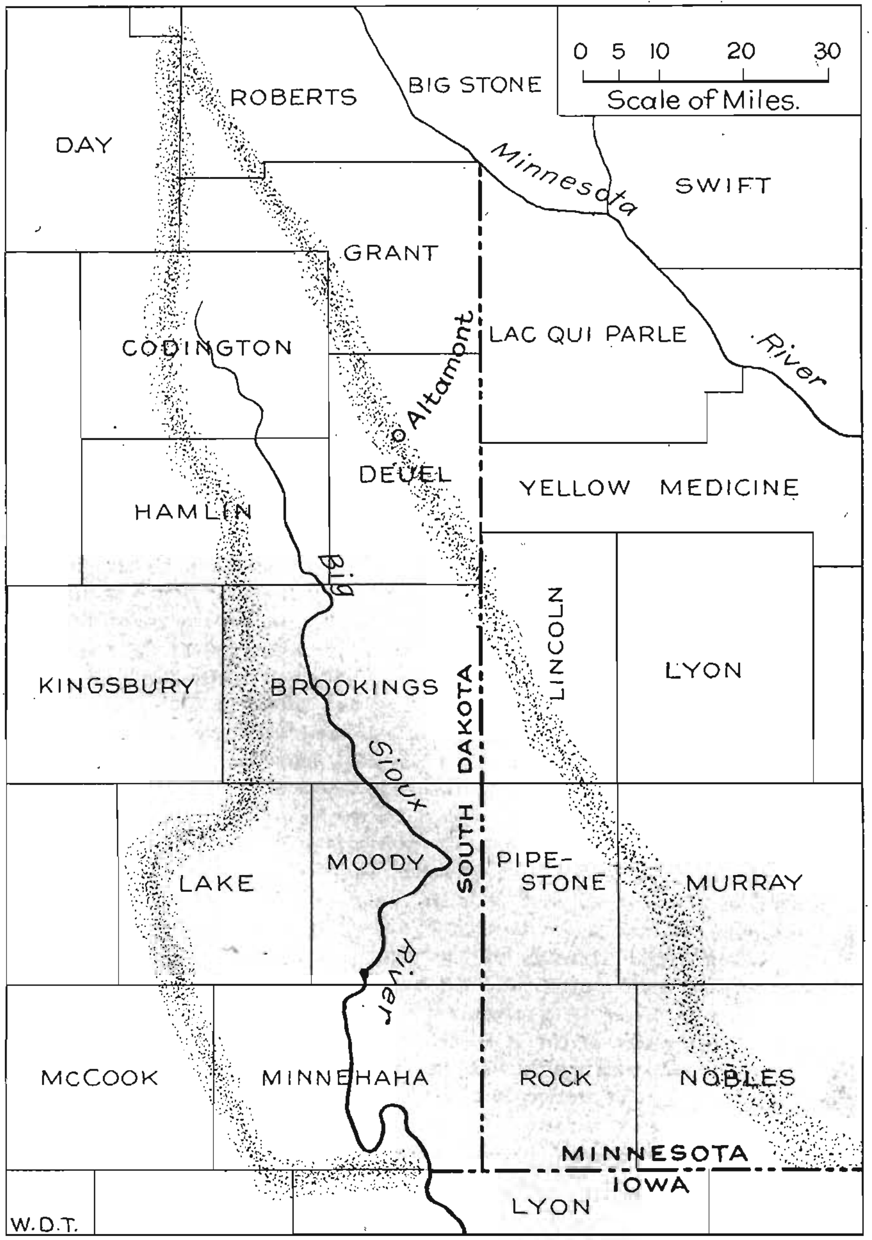
In a report on Nobles county,[31] Warren Upham mapped a belt of terminal moraine running west of north across the county. The outer (west) boundary of this moraine is shown by the heavy broken line in figure 36. In Ransom township it is about two miles farther east than the Wisconsin drift-boundary as traced by the writer, but farther north in central Dewald township it intersects the Wisconsin boundary, and in northwest Dewald township is west of the Wisconsin drift boundary.

Farther northwest the Wisconsin boundary is probably approximately the outer edge of the Altamont moraine, at the crest of the Coteau des Prairies, as mapped by Upham and N. H. Winchell, through northern Nobles, western Murray, northeastern Pipestone and southwestern Lincoln counties (Plate XVII).[32] The Coteau des Prairies rises northward until in southwestern Lincoln county it is 300 to 500 feet above the plain to the west and 200 to 300 feet above the plain to the east. In South Dakota the boundary passes north by northwest through Altamont to the head of the Coteau in southwestern Roberts county (Plate XVII).[33]

Mr. Frank Leverett retraced this Wisconsin drift-boundary through eastern South Dakota and southwestern Minnesota in 1912 in connection with his work for the U. S. Geological Survey, but his report is not yet published. His boundary across Ransom and Dewald townships of Nobles county is practically identical with that traced by the writer.

The Wisconsin drift-boundary crosses the state line half a mile west of Bigelow, Minnesota, in section 36 of Ransom township, Nobles county (figure 36). It extends along the east and northeast borders of a low marshy area that covers the west half of section 36, section 35, and the south half of section 26, and from the northwest corner of this marshy area in the northeast quarter of section 27, the boundary extends west of north through the central part of section 22, and diagonally across the west half of section 15. In the south-

[31]Upham, Warren, Geol. and Nat. History Survey of Minnesota, Vol. I, Pl. 21. 1884.
[32]Geol. and Nat. History Survey of Minnesota, Vol. I, Pls. 21, 24 and 27, 1884.
[33]Todd, J. E., The Moraines of the Missouri Coteau: U. S. Geol. Survey Bull. 144, Pl. 1, 1896.



Map of southwestern Minnesota and eastern South Dakota showing the course of the Altamont moraine. The part in Minnesota is after Upham and N. H. Winchell, that in South Dakota is after Todd.

east quarter of section 9 the boundary reaches the valley of Little Rock river and follows this valley north through the east part of sections 9 and 4 and into section 33 of Dewald township. Here Little Rock river heads northeastward into the Wisconsin drift-area and the boundary extends up a tributary from the north across the central part of section 33, and continues northward along the east side of a broad sag through the west part of section 28, along the west line of section 21 and through the east part of section 17. As it is seen from the south line of section 8, the boundary continues northward down a small valley across the central part of section 8 and the west part of section 5.

For most of this distance through Ransom and Dewald townships, a ridge-like area of Wisconsin drift lies just inside the boundary, and east of this at a distance of a mile to a mile and a half from the boundary, a more or less connected low area parallels the ridge. Small creeks flows north or south in this low area, and then break out through the ridge to the west. The headwaters of both Kanaranzi creek and Little Rock river in Dewald township have valleys of this type. The Wisconsin drift topography of the eastcentral part of Ransom township near the boundary is characteristically glacial but not terminal moraine; but in the north part of the township an area of rough terminal moraine begins and continues northward into Dewald township. A similar area extends eastward into Worthington and Bigelow townships.

Along most of the distance across these two townships a drainage channel parallels the drift-boundary. For two miles north of the state line it is the lowland area that drains southward into Otter creek. Thence for two miles, through sections 22 and 15, there is no valley along the boundary but at the southwest corner of section 9 the boundary touches the valley of Little Rock river and from here northward as far as the boundary was traced, a drainage line lies just to the west. Small deposits of gravel and sand were seen at a number of places along the boundary but there are no great deposits.

The most typical Wisconsin till of this area north of the state line is loose, sandy clay with many pebbles and occasional pockets of sand and gravel. At some places it is more compact but will pulverize to a mealy clay. The older till is plastic brownish yellow clay. West of the Wisconsin boundary the usual topography of the Kansan drift-plain is found. It is moderately rolling in western Ransom township, but north of Rushmore in Dewald township it is only slightly rolling. The drainage of the region is to the southwest, normal to the Wisconsin drift margin and the great watershed, to Rock river. The opposite slopes of Little Rock river valley in section 9 of Ransom township present a good contrast of the Wisconsin and Kansan drift topographies. The east slope is uneven, with glacial hills, and rises to the uneven crest line of the ridge in the east part of section 10. The west slope rises steeply and abruptly to an even crest line.

Summary.—As shown in plate XV the Wisconsin drift-boundary within our region makes some peculiar bends and angles. The direction and alignment of the boundary south of Linn Grove and north of the bend east of Sibley are the same, but between these points there is a great reëntrant of the boundary reaching twenty miles to the east. Within this reëntrant the boundary makes two abrupt bends, east of Dickens and east of Milford, and along the south side of this reëntrant the boundary follows all the bends of the Little Sioux valley. A proper interpretation of the entire course can be expected only after a thorough study of the Des Moines lobe, not only in Iowa, but also in southern Minnesota. It seems probable that the boundary is made up of parts of the margins of several lobes which were contemporaneous or followed each other closely, and that the several abrupt turns are at the angles where these lobes joined each other.

North of where it enters Iowa the boundary extends for a great distance along the side of a lobe in a direction east of south, but ten miles south of the state line it turns east rather abruptly and extends east across the front of the lobe through eastern Osceola and western Dickinson counties. An offset of two miles where it crosses the Ocheyedan valley, and a reëntrant around the head of the Milford flat are readily explained. The edge of this lobe probably ran east or northeast from Milford. The probability of a lobe of ice occupying the site of the Okoboji lakes was noted on page 276.

The change in direction of the boundary to a course almost due south, just east of Milford, seems to be due to the intersection of the edge of the lobe which has just been described with the west edge of another, minor lobe. The edge of this lobe forms the boundary for twelve to fifteen miles southward, where it changes direction and extends eastward across the front of the lobe past Dickens.

East of Dickens, in central Freeman township, this eastward course is again crossed by the west edge of the great Des Moines lobe, which is marked by the strong terminal moraine (Ruthven moraine) along the east lines of Dickinson and Clay counties. From a point east of Dickens, the west edge of the Des Moines ice lobe extended southwestward across southeastern Clay and northern Buena Vista counties and for most of the distance from Gillett Grove to Linn Grove, the ice edge lay along the course of the Little Sioux valley. From western Buena Vista county, the west edge of the lobe had a course east of south across Buena Vista and Sac counties, and southeast across Carroll and Guthrie counties.

The course of the Wisconsin boundary from the point where it turns northward in East Holman township of Osceola county to the head of the Coteau des Prairies in southwestern Roberts county, South Dakota, a distance of 160 miles, is very uniform and marks the western limit of a single ice-lobe, in contrast with the several minor lobes which apparently formed the boundary in northwestern Iowa.

COMPARISON OF THE COURSE AS RETRACED, WITH EARLIER TRACING.

The work of the writer in Sac and Buena Vista counties, in so far as the location of the Wisconsin drift-boundary is concerned, essentially verified the work of Professor Macbride, as the location of the boundary was changed only locally. The greatest changes were in showing that the Wisconsin ice pushed up to the edge of Brooke creek valley in Elk and Brooke townships of Buena Vista county, and farther northwest into the angle between Brooke creek and the Little Sioux river valleys, and in shifting the boundary two miles farther west on the south side of Wall lake outlet.

The course in eastern Clay county is also essentially that given by Professor Macbride in his discussion of the "Wisconsin Margin," in the report on Cherokee and Buena Vista counties, which is, however, very different from the earlier interpretation given in the report on Clay county. The map published by Professor Macbride in the report on Cherokee and Buena Vista counties is reproduced as figure 28 on page 249. The scale of this revised map is so small that exact comparison of borders is not advisable, but the boundary between the "Knobby Drift" and the "Wisconsin Drift Plain" divisions of the Clay county map in Logan and Freeman townships must have been the line used later as the margin of the Wisconsin area, and this boundary is incorrect in several places. Elk creek valley should form the boundary of the "Knobby Drift" area of Logan township, and an area of eight to ten square miles in northern Logan and southern Freeman townships, that is either flat outwash plain or slightly rolling Kansan drift-plain, was included in the "Knobby Drift" division.

North of Dickens the boundary as traced by the writer diverges from that of Professor Macbride, and there is no further correspondence of the two northward to the state line. In his discussion of the Wisconsin margin noted above, Macbride carries the boundary west from Dickens past Spencer to Everly, and thence up the northeast bank of the Ocheyedan to the state line (figure 28). No discussion of this course is given by Professor Macbride and since it does not agree in any way with his earlier mapping in these counties, one is left to infer or search out in the field the evidence upon which this interpretation may have been based. The north part of Clay county and southwestern Dickinson are quite level, and probably were considered Wisconsin for this reason. In fact the northern part of Clay county north of Spencer shows flat marshy areas, but these are not of the type found in the enclosed basins of the Wisconsin drift-region. Belts of low rounded hills lie north of the Spencer flat in Sioux township, north of the Ocheyedan plain in Riverton and Lone Tree townships, and at the edge of the Ocheyedan valley in the southeast corner of Osceola county, along the course of Macbride's revised moraine, and this probably constitutes part of the evidence for the location of the moraine. The hills of these belts are, however, sand hills and are not morainic (page 330).

This retracing of the Wisconsin drift boundary left outside the Wisconsin area the whole of the level region of Clay, O'Brien and Osceola counties which had been called the extra-morainic Wisconsin. Although it fixed a definite Wisconsin boundary, it left unsolved the problems of the extra-morainic area, except that in fixing the boundary, it made this area west of the boundary, pre-Wisconsin. This retracing also left outside the Wisconsin area the hills in Waterford township in northwestern Clay county, which contain much sand and gravel, and the gravelly kamelike hills of northeastern Lyon county. This extra-morainic region and its problems will be considered in Chapter III.

The Wisconsin Drift in the Region of Sioux Falls.

EARLIER WORK.

In 1883 Professor Chamberlin, in his paper on the Terminal Moraine of the Second Glacial Epoch,[34] traced the moraine on the east side of the Dakota lobe southward from the head of the Coteau des Prairies in northeastern South Dakota (figure 26) to a point in northwestern Lincoln county southwest of Sioux Falls. Then, attributing the determination to Professor Todd, he states that the moraine "bears eastward to the vicinity of the Big Sioux River, and thence follows the hilly tract bordering its west side southward into Union county." This brings the Wisconsin drift-region to the edge of the Big Sioux valley opposite Lyon county.

In 1896, Professor Todd, in bulletin 144 of the U. S. Geological Survey, mapped a belt of "Morainic Surface", which, from the Big Sioux valley opposite the Iowa state line, extends west along the Minehaha-Lincoln county line and thence northwest across the southwest corner of Minnehaha county. It is shown by the shaded area in figure 37. In bulletin 158 (1899), of the same series, Professor Todd showed the morainic belt as on the earlier map, and described (page 35) "a high massive ridge" as beginning on the west side of the Big Sioux, one mile north of the Iowa-Minnesota state line and extending west along the course shown in figure 37. This ridge was interpreted as the northeast boundary of the Dakota lobe of the Wisconsin drift-plain. The area to the northeast, including Sioux Falls and beyond, lies between the Dakota and Des Moines lobes. The maps of Professor Todd show also two patches of morainic surface northeast of Canton and a belt extending from a point south of Canton southwest through Beresford (figure 37).

In 1900 Professor Wilder studied the Geology of Lyon county, in the northwest corner of Iowa.[35] He accepted the mapping of the Dakota plain opposite Lyon county as Wisconsin drift, and further enlarged the area in two ways; first by showing a belt of Wisconsin drift and a patch of Altamont moraine in western Lyon county, and second by placing the boundary, on the Dakota

[34] U. S. Geol. Survey Third Ann. Report., pp. 394-395.
[35] Iowa Geol. Survey, Vol. X, pp. 137-141 and map, p. 118.

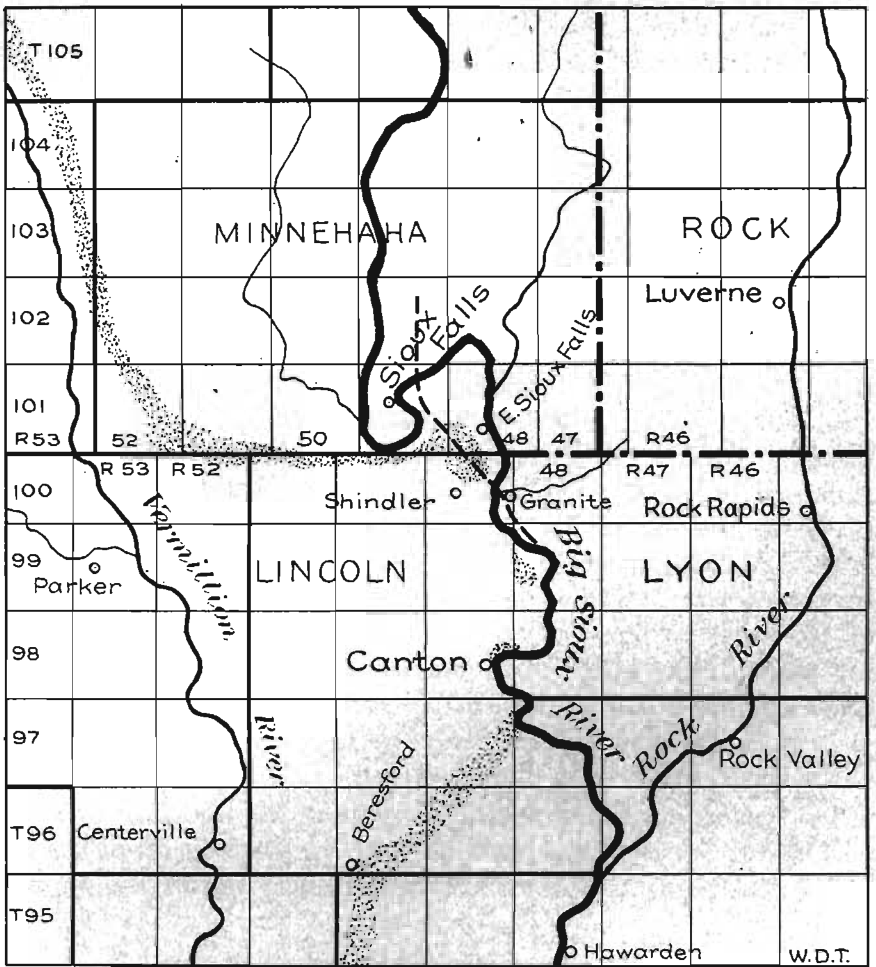


FIG. 37. Map showing a portion of eastern South Dakota and adjoining parts of Iowa and Minnesota. The shaded area shows the course of the Altamont Moraine as mapped by Todd in bulletins 144 and 158, U. S. Geological Survey. The broken line is the course of the Altamont Moraine as described by Wilder in the Lyon county report of the Iowa Geological Survey, volume X.

side, east of Sioux Falls. This so-called Wisconsin drift area of western Lyon county, as shown on the map of the surface deposits of the county, begins at the mouth of Blood Run, west of Granite, and continues south two miles as a belt about half a mile wide and thence three miles farther to the southeast as a narrow belt less than a quarter of a mile wide. At the north end of the belt, a circular area of Altamont moraine was mapped. Concerning the Wisconsin border on the Dakota side, Wilder says (page 141), "From the point where the moraine crosses the river, west of Granite, to Sioux Falls it is easily traced as a well defined, bowlder-strewn ridge. It passes east of Sioux Falls and crosses the river two miles northeast of the town. Thence for ten miles it was traced nearly due north." The course of this border located from the statement just quoted is shown by a heavy broken line in figure 37.

When the writer examined this Wisconsin drift area and Altamont moraine of western Lyon county, about half of the area mapped as Wisconsin was found to be on a terrace of the Big Sioux valley with nothing more suggestive of a moraine than Indian mounds, and the remainder is on a steep slope of a rugged upland in a topography that is a combination of eolian and erosional work. The hills in the northeast quarter of section 26, Sioux township, which were discussed by Wilder and were interpreted as morainic mounds, are Indian mounds. Most of them have been opened, and shells and fragments of bones lie on the slopes of many of them. The only features found along the front of the bluff which might suggest morainic hills are some shoulders well up toward the top. These have a common altitude and although from below they look like mounds, from above their character is plainly seen.

The conclusion of the writer was, therefore, that this area is not Wisconsin drift and that no part of the Wisconsin drift-plain of the Dakota lobe exists on the Iowa side of Big Sioux river.

Only a few weeks later Professor Shimek of the Iowa Geological Survey, working independently of the writer and upon other problems, examined this Wisconsin area of western Lyon county and reached the same conclusions concerning it. But Professor Shimek went much further in his restriction of the Wisconsin area, and among the conclusions of his paper, is the following:[36] "The plain extending from Shindlar to Canton, South Dakota, is Kansan and not Wisconsin". This is an area that was included by Chamberlin, Todd and Wilder in the Wisconsin drift-plain, and the writer in traveling across it by rail had seen what he thought to be conclusive evidence of Wisconsin

[36]Shimek, B., Bulletin of Geol. Society of America, Vol. 23, p. 154, 1912.

age. If this is not Wisconsin drift, it seemed as if serious inroads would have to be made upon the Wisconsin drift-plain of Dakota. It therefore seemed worth while to examine this Dakota plain opposite Lyon county to try to determine the identity of the Wisconsin drift-plain and then to locate more exactly its boundaries, for as was noted above, the statement of Professor Wilder concerning this boundary does not agree with the mapping of Professor Todd.

The results of this study on the Dakota side have already been published in another place,[37] but since the region concerned is so close to our area, and since the criteria upon which the identification of the Wisconsin drift-plain of Dakota is based are the same as those used for the identification of the Wisconsin drift-plain to the east in Osceola and Dickinson counties, it seems worth while to include here the treatment of this area.

CHARACTERS OF THE WISCONSIN DRIFT-PLAIN.

The western part of Lyon county, Iowa, is very rugged, with a submaturely dissected topography. The narrow divides stand at an altitude of 1400 to 1480 feet above sea level and below this there is a relief of 100 to 150 feet. The surface material is loess, and the drift exposures are of yellow Kansan clay. The eastern portion of Lincoln county, South Dakota, opposite Lyon county, is, however, a relatively level plain, sloping gently to the south and east. Near its eastern margin at the Big Sioux there are a few narrow valleys, but the dominating feature of the region is the relatively level plain. This plain has no loess covering. The high divides on the east side of the river, from the state line south to a point opposite Canton, have a uniform elevation of about 1460 feet above sea level. Opposite the state line the elevation of the Dakota plain is about 1400 feet, which is about 150 feet above the river and about 60 feet below the Iowa divides. But the elevation of the plain decreases southward more rapidly than the river falls, and north of Canton the edge of the plain overlooking the valley has an elevation of only 1320 to 1340 feet, which is only eighty to ninety feet above the river and more than a hundred feet below the divides of the

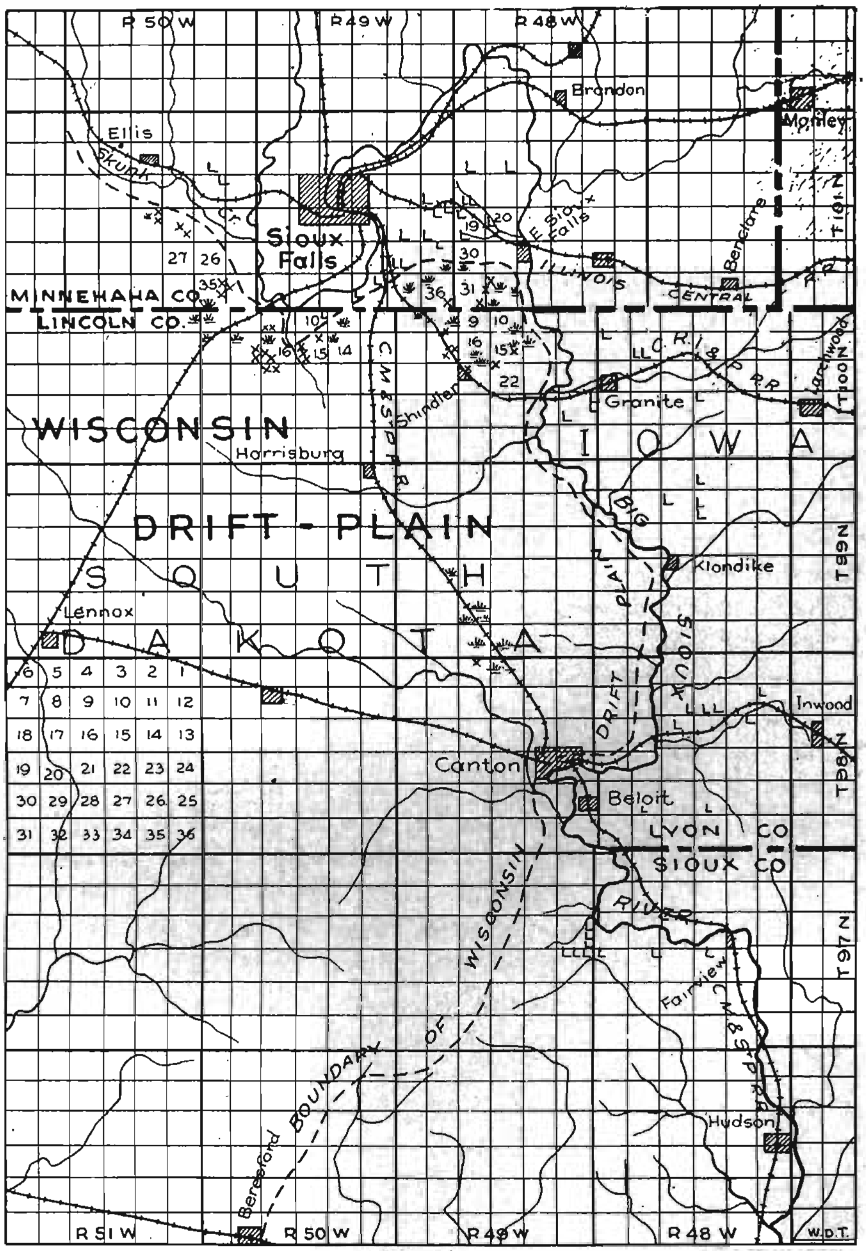
[37] Carman, J. E., The Wisconsin Drift-Plain in the Region about Sioux Falls: Proc. Iowa Academy of Science, Vol. XX, pp. 237-250, 1913.

Iowa side. These contrasts in the topography and elevation of the areas on opposite sides of the Big Sioux river are well shown in the northeast corner of the Canton topographic sheet of the U. S. Geological Survey.

Directly east from Sioux Falls, the topography is erosional with a relief of fifty to seventy-five or even a hundred feet. The distance between the two limbs of the northward loop of the Big Sioux valley is here only four to six miles (Plate XVIII), and the small creeks have cut back from either direction until all the area is well drained. The slopes are moderately steep, but rounded, indicating submature dissection; the region is covered with loess, which is seen in many road-cut exposures; the surface material, which is derived from the loess, is without grit of any sort; and no pebbles or bowlders appear at the surface. In the more dissected parts, near the large valleys, the fresh, brownish gray phase of the Kansan drift can be exposed. The region belongs to the loess-covered Kansan drift-plain.

Extending in an east-west direction through sections 30 and 29 of Township 101 North, Range 48 West, southwest of East Sioux Falls, is a ridge which rises to an elevation approximately that of the major divides to the north, has a rounded crest and apparently is erosional. The north slope has broad valleys leading down to the creek of sections 19 and 20, the bed of which is 100 feet lower than the crest of the ridge. This is the ridge described by Professor Todd (page 294) and interpreted by him as a part of the outer moraine. From the crest of this ridge one overlooks the region to the north and the south. To the north is the rolling country of erosional topography noted above. To the south of the crest, the slope descends thirty to fifty feet in the first half mile and then an even plain of slight relief continues to the south and southwest.

In sections 31 and 32 (Township 101 North, Range 48 West), on this plain, there is a relief of fifteen to twenty-five feet, with many undrained depressions which during the wet season contain small ponds (Plate XVIII). Just east of the southwest corner of section 32 there is a small depression occupied by a pond and not more than fifty yards from the edge of a narrow valley which is cut to a depth of thirty to forty feet below the plain.



Map of the Sioux Falls-Canton region. The broken line shows the eastern boundary of the Wisconsin drift-plain in Dakota. L—loess exposures, X—bowlders, ѱ—undrained depressions.

Other ponds lie just to the east in similar positions with reference to this valley, and at the quarter-section corner on the east of section 32 is an undrained depression within a short distance of the edge of the Big Sioux valley. This plain continues southward and southwestward to Shindler and beyond. North of Shindler the relief is ten to twenty feet, and undrained depressions with swamps are present in every section. The location of a number of these is shown in Plate XVIII. Typical examples appear in the southeast corner of section 36, Township 101 North, Range 49 West, the southwest and southeast quarters of section 31, Township 101 North, Range 48 West, the northwest corner of section 9, the east part of section 8, and at several places in sections 17, 8 and 7, all in Township 100 North, Range 49 West, along the Chicago, Rock Island and Pacific railway northwest of Shindler.

The loess loam, so usual in the Kansan area, is absent here, and the drift continues to the surface, or is overlain by black soil. A field in the southeast quarter of section 31 showed a gravelly, pebbly soil turned up by recent plowing, and the road beds contain pebbles and sandy material which produces a grating sound beneath wagon wheels. A few bowlders lie on the surface or have been gathered up and piled along the fences. These may be seen along the west line of section 32, southwest of East Sioux Falls, in sections 22 and 15, east of Shindler, and a pile of them may be seen from the railway train just southeast of the station at Shindler. They are numerous in sections 15 and 16 of township 100 north, range 50 west, and were seen at a number of places farther northwest (Plate XVIII).

The erosion valleys of this plain are narrow and steep sided. They are found only along the Big Sioux valley, and even here have determined the topography of only a small part of the area they drain. The usual relief features of the plain are low hills and broad swales interspersed with shallow undrained depressions. Most of the broad swales are followed by streams, but these streams did not make the valleys which they occupy. They made only the narrow, shallow channels in which they flow. The low hills and ridges show by their position and form that they were not made by erosion, but that, like the broad winding depressions in which the streams flow, they are constructional.

Sufficient characters have now been given to indicate the type of plain with which we are dealing. It is a glacial plain with very definite characters, and is in decided contrast with the erosional area to the north, and with the region on the Iowa side.

THE WISCONSIN DRIFT-BOUNDARY NEAR SIOUX FALLS.

The boundary between the erosional topography and the glacial topography is not sharp in all cases, but the transition from the one to the other takes place within a quarter to half a mile. The boundary is shown in Plate XVIII by a heavy broken line. From the Big Sioux valley about a mile south of East Sioux Falls it extends westward through the south parts of sections 29 and 30 along the south base of the ridge described on page 302. In the east part of Sioux Falls township (T. 101 N., R. 49 W.) its course changes to southwest, parallel with the Big Sioux. It continues in this direction for about four miles, to the northeast part of section 16 of Township 100 North, Range 50 West and thence bends abruptly to the north and follows a small creek valley through section 9 to the Big Sioux. Southeast of this boundary there is a slightly rolling glacial plain with undrained depressions and many bowlders, and drift extends to the surface. To the northwest the surface is rolling to rough, is entirely controlled by drainage lines and the material at the surface is loess or pebbleless loam.

From the mouth of the creek valley on the north line of section 9, the boundary is the edge of the Bix Sioux flood-plain west and north to the union of Skunk creek valley with the Big Sioux valley. From here the border lies along the south edge of the Skunk creek flat, and extends northwest through the center of Township 101 North, Range 50 West. The part of this township to the south of Skunk creek is an undissected glacial plain while that to the north is maturely dissected and the surface exposures are of loess. The contrast of the topographies on opposite sides of this valley is very pronounced and furnishes an excellent example of glacial versus erosional topography.

In this entire distance along the Wisconsin margin from the Big Sioux opposite the state line to the center of Township 101 North, Range 50 West, a distance of fifteen to seventeen miles, there is not a single hill that might be called a terminal moraine hummock, and the marginal part of the glacial plain is no more uneven than that more distant from the margin, except for irregularities due to recent erosion or to incomplete obliteration of pre-Wisconsin surface features.

Professor Todd described the course of the "outer moraine" across this area in the following words:[38] "Beginning on the west side of the Big Sioux, about a mile north of the northern boundary of Iowa, a high massive ridge begins to extend westward and southwestward around the Great Bend of the Big Sioux, and continues its westerly course to near the southwest corner of township 101, range 51." Near the Big Sioux valley, south and southwest of East Sioux Falls this ridge is prominent, but it is less prominent westward and in southeastern Sioux Falls township is represented only by disconnected hills. These features, apparently taken by Professor Todd as morainic, are all on the Kansan drift just beyond the actual Wisconsin drift-margin and are not morainic, but erosional. However, the contrast between the glacial plain to the south and the erosional topography to the north was detected and its true significance realized. Professor Todd states that westward from the Great Bend, this ridge "continues its westerly course to near the southwest corner of township 101, range 51." A broad ridgelike elevation does continue westward along the county line from the Great Bend, but this elevation does not mark the margin of the Wisconsin drift, for as noted above the southern part of township 101 North, Range 50 West, south of Skunk creek, belongs to the Wisconsin drift-plain.

THE DRIFT.

This separation of the Kansan and the Wisconsin drift-plains is based on physiographic features, although the bowlders of the Wisconsin drift and the loess-covering of the Kansan areas are contributory lines of evidence. The Wisconsin drift is very hard to distinguish from the Kansan, at least in the marginal

[38]U. S. Geol. Survey Bull. 158, p. 35.

part of the Wisconsin drift-area, or else the Wisconsin drift is very thin. In a few places the drift observed is not the typical Kansan and may be Wisconsin; but most of the exposures studied apparently are Kansan. On the basis of the characters of the drift alone one would not separate the areas; but the conclusive evidence is the topography, and with this agree the absence of a loess-covering over the Dakota plain, the presence of bowlders on the surface, and the questionable drift of the region.

Southeast of Shindler, along the Chicago, Rock Island and Pacific railway, where it descends to the Big Sioux valley, there are a number of drift cuts. The plain above is Wisconsin, but the drift exposures are Kansan with the possible exception of the first cut southeast of Shindler, which is at the very edge of the plain just where the descent begins. In this cut, there is near the surface, loose, sandy drift which breaks out in rounded fragments and crumbles to a sandy, mealy clay when crushed in the hand. It grades downward to a harder, more plastic clay, which breaks with the more definite Kansan fracture.

Just south of the northwest corner of section 36 of Sioux Falls township (Township 101 North, Range 49 West), yellowish brown sandy drift comes to the surface, except for a thin covering of soil. This is just inside the Wisconsin drift area and good glacial topography continues to the southeast. Only half a mile to the west but beyond the Wisconsin drift-boundary a road cut showed a loess-covering four to six feet thick over the Kansan drift (Plate XVIII).

At the northeast corner of section 10, Township 100 North, Range 50 West, just outside the Wisconsin drift-margin, there are several cuts in loess, one of which is twelve feet deep, and some of them show Kansan drift below the loess. About eighty rods south, a road-cut shows, at the surface, brownish gray drift with considerable sandy material and a few pebble bands. Eight feet lower on the slope, the drift rests on brownish yellow loess several feet in thickness, the base of which is not exposed. Apparently the Wisconsin ice overrode loess at this place, and covered it with Wisconsin till.

We are accustomed to think of the drifts of different ice-epochs as presenting each its own characteristic lithological features, but if two ice-sheets advanced over the same route and eroded the same rock formations, there is little reason why the drifts should differ in composition. The Wisconsin drift was obtained from the same rocks as the Kansan drift, or is in large part simply reworked Kansan drift, so that we should not expect the two sheets of drift to be distinctly different. However, it is not believed that any large amount of the drift exposed in the deeper cuts, as along the railway southeast of Shindler, is Wisconsin. It is believed rather, that the amount of Wisconsin drift is small, amounting to only a few feet of material, much like the Kansan, and grading downward into the latter. Detailed work in the region will probably show that the Wisconsin drift differs slightly from the Kansan, so that it will be possible to differentiate them, but should this not prove true, the glacial plain remains, and this cannot be Kansan. It is a youthful glacial plain and nothing of this type is found in any known Kansan drift-region.

The Chicago, Milwaukee and St. Paul railway, extending south from Sioux Falls, crosses the border of the glacial plain just north of the county line, and continues southward across this plain through Harrisburg to Canton. At a number of places along this road swamps may be seen, and bowlders lie on the surface. It is evident that if the identity of the Wisconsin plain is established farther north, it should continue south to Canton. The writer has not seen the region southwest of Canton, but from the topographic map of the area it seems evident that the southeast border of this plain is approximately as given by Professor Todd, that is it runs from the point of the upland south of Canton, south by southwest through Beresford.

ABSENCE OF LOESS.

It has been noted already that loess is absent over the Wisconsin plain, but the matter is of such importance that a more complete statement is justified. The rugged region of the Iowa side is loess-covered, with numerous exposures in the road-cuts. The area within the east loop of the Great Bend between Sioux

Falls and East Sioux Falls, the area within the west loop of the Great Bend and that west of the Big Sioux and north of Skunk creek, are all loess-covered, as is also the rugged area south of Canton. In contrast with this loess-covered rugged area the Dakota plain is free from loess. In Plate XVIII there are mapped twenty exposures of loess in the area north of the Wisconsin drift-plain to the east and west of Sioux Falls, nineteen exposures on the Iowa side, and nine exposures in the rugged area south of Canton.

Many of the loess exposures of Plate XVIII are taken from a map by Professor Shimek.[33a] On this map, Professor Shimek shows but one exposure of loess in the area which is included within the Wisconsin drift-plain of Plate XVIII, and this one is just at the edge of the Wisconsin drift-plain, in or near the west bluff of the Big Sioux valley. On the other hand he shows twelve exposures of loess within the east loop of the Big Sioux, sixteen along the Iowan upland between the state line and a point opposite Canton, and eleven in the upland south of Canton. The plotting of these loess exposures brings out the fact that the loess-covered area is identical with the area of erosional topography, while the area without loess is identical with that having a glacial topography.

SUMMARY.

The results of this study would fix the extent of the Wisconsin drift-plain essentially as determined by Professor Todd. The writer does not, however, agree with Professor Todd concerning moraines at the edge of the Wisconsin plain. It has been shown that the features taken by Todd as the Altamont moraine, from a point opposite the north boundary of Iowa westward to the south end of the Great Bend, are erosional hills and ridges of the Kansan plain just outside the Wisconsin boundary, and that the ridge stretching westward from the south end of the Great Bend is within the Wisconsin boundary since it has glacial topography to the north, as far as the valley of Skunk creek. The isolated hills along the west side of the Big Sioux between East Sioux Falls and Canton, called Altamont moraine by Todd, apparently are remnants of the Kansan plain, which

[33a] Bull. Geol. Society of America, Vol. 23, p. 131.

are made up of Kansan drift but were over-ridden by the Wisconsin ice. It is also probable that there is little true terminal moraine along the border southwest of Canton toward Beresford.

In summary, the evidence submitted may be brought together as follows:

(1) The Dakota plain has a slightly rolling surface, with a relief of fifteen to twenty-five feet, while the region to the north, east and southeast, is rugged with a relief of 100 to 150 feet.

(2) The Dakota plain has an altitude fifty to a hundred feet below the altitude of the divides of the adjoining regions to the north, east and southeast.

(3) The relief features of the Dakota plain are principally low mounds and broad swales, interspersed with shallow undrained depressions. The few erosion valleys are narrow and steep sided and have determined the topography of only a narrow belt on either side. This is a definite glacial surface and the time which has elapsed since its formation is comparatively short. The relief features of the adjoining region are those produced by erosion by running water and have advanced to the submature stage of the cycle.

(4) The Dakota plain is free from loess, while the region to the north, east and southeast has a loess covering.

(5) Bowlders and bowlderets are numerous on the Dakota plain, while in the area to the north, east and southeast, bowlders are rare, except in the beds of ravines that are being actively degraded.

(6) The Dakota plain has a dark, pebbly, gritty soil, while over the surrounding area there is a pebbleless loam derived from the loess.

This combination of characters found on the Dakota plain calls for an entirely separate glaciation at a very recent geologic time. The conclusion then is, that the plain extending from the boundary along the north line of Lincoln county, south through Shindler and Harrisburg to the upland south of Canton, and east to the Big Sioux valley, was covered by a part of the Dakota lobe of the Wisconsin ice-sheet and is a Wisconsin drift-plain, while the areas to the north, east and southeast belong to the loess-covered, maturely eroded Kansan drift-plain.

As mapped by Professor Todd the east edge of the Dakota lobe, from the head of the Coteau des Prairies extended southward through Codington, Hamlin and Brookings counties along the west side of the Big Sioux valley, as shown in Plate XVII.[39] The Altamont moraine was mapped as offsetting fifteen to twenty miles to the west in northern Lake county and then continuing southward, at a distance of twenty to thirty miles west of the Big Sioux, through western Lake, northeastern McCook and southwestern Minnehaha counties, and eastward along the south line of Minnehaha county to the Big Sioux valley. From the results of the work on the Dakota side noted above (page 301), which show that the boundary extends northwest along the south side of Skunk creek, and from the description of western Minnehaha and Lake counties given by Professor Todd,[40] the writer is led to believe that the actual boundary of the Wisconsin drift continues northward across western Minnehaha and eastern Lake counties and does not make the offset which the moraine may make.

Mr. Leverett retraced this east boundary of the Dakota lobe in 1912 but his results have not yet been published. His work verifies the tracing of that part of the boundary given above (page 301).

The distance between the Des Moines and the Dakota lobes of the Wisconsin ice at the north line of Iowa was forty-six miles, but they remained separate 150 miles farther north. The area between these two lobes contains the headwaters of the Big Sioux river. The Altamont moraine of the Des Moines lobe in Minnesota is located approximately on the earlier divide, and the water draining southwestward from the Des Moines ice lobe was stopped by the edge of the Dakota lobe. The various streams were here united, and flowing southward along the course of Big Sioux river, carried away the drainage of the two ice-edges.

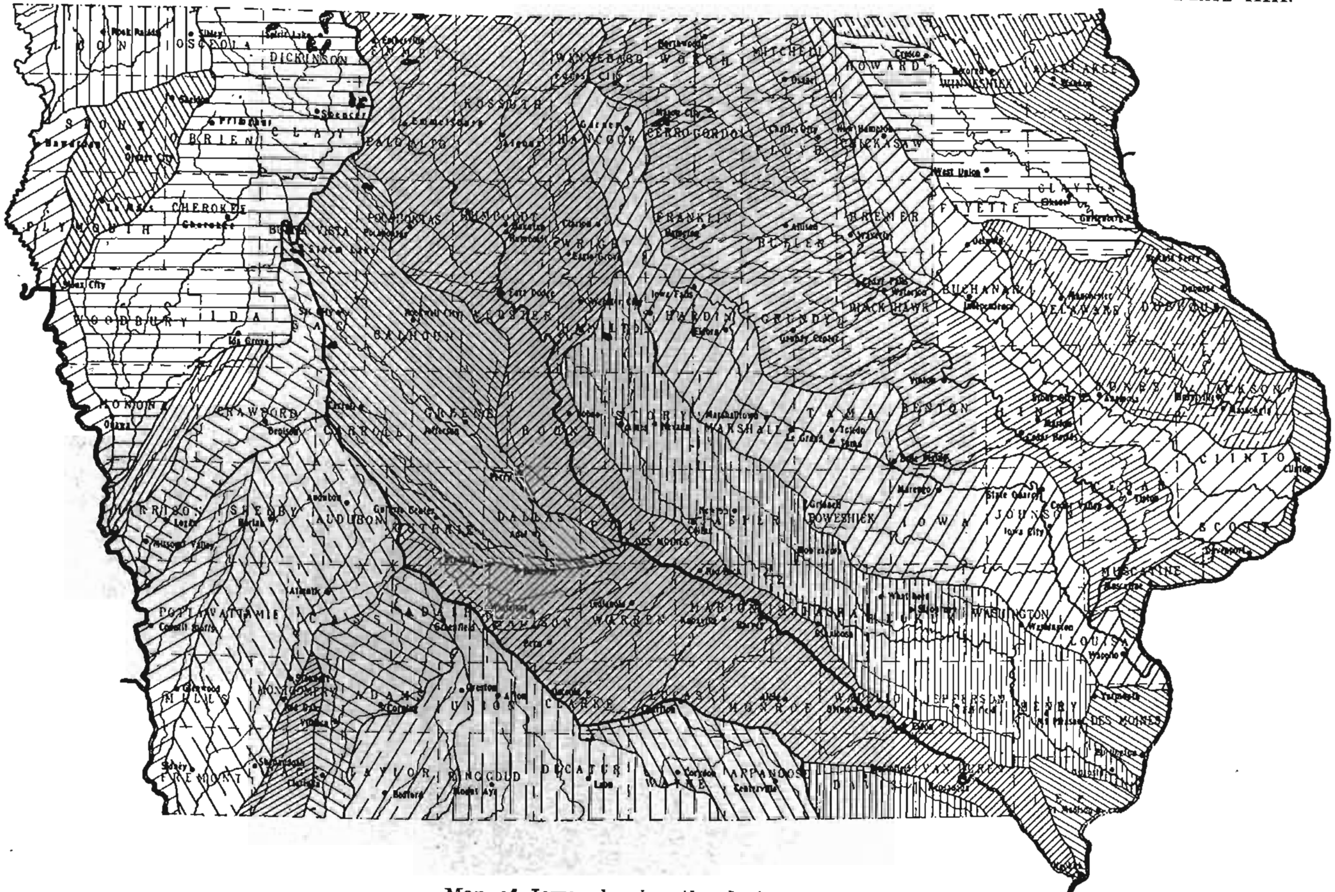
[39]U. S. Geol. Survey Bull. 144, Pl. 1.
[40]U. S. Geol. Survey Bull. 158, p. 36.

Drainage Changes Caused by the Wisconsin Ice.

The eastern three-fourths of the state of Iowa drains southeastward by long parallel streams to the Mississippi river. The western quarter of the state drains southwest by south through shorter streams to the Missouri river. The parallelism of the major streams both to the southeast and to the southwest is a notable feature of the drainage of Iowa (Plate XIX). The divide between these two great drainage basins has a northwest-southeast direction through southwestern Iowa, but in western Carroll county, it takes a more northerly course which is followed to the Minnesota state line.

The divide intersects the south boundary of Sac county east of the middle of the south line of Viola township, crosses the east end of Wall lake outlet and extends northward through central Sac county, forming the divide between Indian creek and Boyer river (Plate XV). It passes westward along the south side of the Storm lake basin and northward along the divide through Alta (Plate XIX). Four miles north of Alta it doubles back around the head of the small creek which enters the northwest corner of Storm lake and extends southeast almost to Storm Lake, rounding the head of Brooke creek, which flows north to the Little Sioux. North of the head of Brooke creek the divide is in the Wisconsin drift-area, and its course to the northward is less definite. It extends north and east through central and northeastern Buena Vista county between the headwaters of Raccoon river on the southeast, and the tributaries of the Little Sioux on the northwest. It crosses the southeast corner of Clay county, follows north along the Ruthven moraine two to four miles east of the west line of Palo Alto and Emmet counties, crosses the northeast corner of Dickinson county and enters Minnesota about five miles west of Des Moines river (Plate XIX).

The divide continues northward in southeastern Jackson county, Minnesota, for twelve miles and then bends westward around the headwaters of the Little Sioux, offsetting twenty-four miles to the west and in this distance swinging six miles to the south. Here, northwest of Worthington, the divide changes its direction to north of northwest, and holds this course for



Map of Iowa showing the drainage basins.

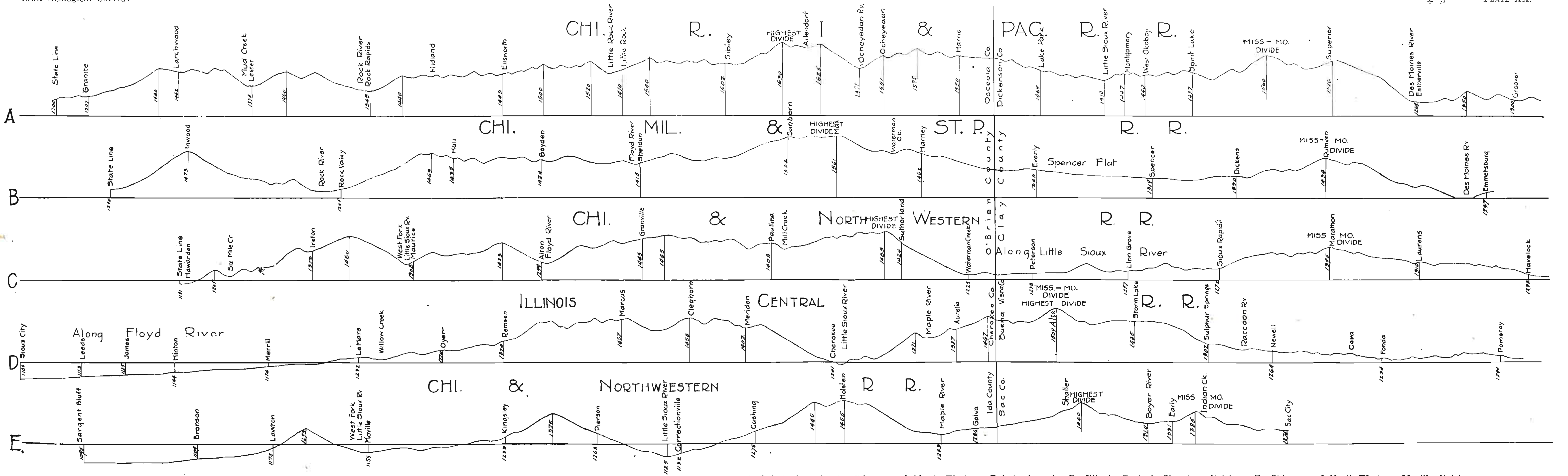
more than a hundred miles along the crest of the Coteau des Prairies.

From the south line of Sac county to Storm Lake the divide is just west of the boundary of the Wisconsin drift-region. North of Storm Lake the divide lies within this drift-region, but, as far as Ruthven it is only five to ten miles east of the boundary. The boundary thence angles westward to such an extent that on the state line the divide is thirty-six miles within the Wisconsin drift-area, but the westward course of the divide across the headwaters of the Little Sioux brings it back to within a few miles of the Wisconsin drift-boundary northwest of Worthington, in which position it continues on to the northwest along the crest of the Coteau des Prairies.

DRAINAGE CHANGES IN THE LITTLE SIOUX RIVER BASIN.

Course of the Mississippi-Missouri Divide.—The Mississippi-Missouri divide northwest of Worthington, Minnesota, agrees in direction with the part south of Storm lake. Between Worthington and Storm Lake a great reëntrant carries the divide to the east about the headwaters of Little Sioux river. But for this irregularity, the course of the divide would continue northward from Alta through western Buena Vista, western Clay or eastcentral O'Brien and central Osceola counties; it would cross the state line just east of Bigelow, Minnesota, and would join the present divide where it changes its direction northwest of Worthington. This raises the question, may this not have been the real watershed of the state. In other words may not the region now drained by the Little Sioux above northeastern Cherokee county formerly have drained southeastward to Mississippi river? Two other lines of evidence, bearing on the subject, should be examined before the question is decided.

Altitude of the Mississippi-Missouri Divide.—The divide between the drainage of Mississippi and Missouri rivers south of Sac county, and of that portion northwest of Worthington is along the highest land between these two rivers; but in most places within the area under discussion this is not true. The range of hills (Ruthven moraine) standing well above the region to the east and west, which forms the divide in western Palo



Profiles of railways crossing northwestern Iowa. A—Chicago, Rock Island and Pacific, Sioux Falls branch; B—Chicago, Milwaukee and St. Paul, Dakota branch; C—Chicago and North Western, Dakota branch; D—Illinois Central, Cherokee division; E—Chicago and North Western, Moville division.

Alto and Emmet counties, has an altitude of 1425 to 1475 feet above sea level, while the watershed west of the Waterman and Ocheyedan drainage basins has an altitude of 1450 to 1500 feet in southeastern O'Brien county, and rises northward to more than 1600 feet in northern Osceola county.

The comparative altitude of these two divides is well shown by a study of the profiles of the railways that cross the region. The Chicago, Rock Island and Pacific railway in the north row of counties crosses the Mississippi-Missouri divide near Superior in northeastern Dickinson county at an altitude of about 1560 feet, but the altitude continues to increase westward until in central Osceola county, just west of the Ocheyedan valley it is about 1630 feet (Plate XX, profile A). The Chicago, Milwaukee and St. Paul railway in the north part of the second row of counties crosses the Mississippi-Missouri divide in western Palo Alto county, near Ruthven, at an altitude of about 1440 feet, but the highest divide is crossed more than thirty-five miles farther west, just east of Sanborn in northern O'Brien county, at about 1560 feet (Plate XX, profile B).

The Des Moines and Sibley branch of the Chicago, Rock Island and Pacific railway crosses the Mississippi-Missouri divide near Leverett, in northeastern Buena Vista county, at an altitude of about 1370 feet, but it continues to rise gradually to the northwest across Clay and northeastern O'Brien counties, and has its highest altitude near Melvin in southern Osceola county at more than 1580 feet. The Dakota branch of the Chicago and North Western railway crosses the Mississippi-Missouri divide near Marathon in northeastern Buena Vista county, at about 1400 feet, but the divide crossed just west of Sutherland in southeastern O'Brien county has an altitude of about 1500 feet (Plate XX, profile C). South of the Little Sioux river the next line is the Illinois Central railway which, at Alta (1509 feet) in southwestern Buena Vista county, attains its greatest altitude within the state on the crest of the Mississippi-Missouri divide (Plate XX, profile D).

All the highest points crossed by the railways in the two north rows of counties are on the divide west of the Little Sioux drainage basin in O'Brien and Osceola counties, along the course, which, as noted above, would be a direct continuation of the divide to the north and south. The evidence therefore of altitude would support strongly the idea that the true watershed of the state should continue west of north from western Buena Vista county through O'Brien and Osceola counties.

Pattern of Drainage.—A study of the drainage map of Iowa (Plate XIX) shows that the streams which flow southeastward to the Mississippi have their upper courses almost parallel with the divide, and draw away from it very gradually while those which flow southwestward toward the Missouri have their headwaters almost normal to the divide. As a result of this difference, almost the whole of the east side of the Mississippi-Missouri divide is drained by the tributaries of Des Moines river, the longest and largest of the southeastward flowing streams, while nearly every important stream of southwestern Minnesota and western Iowa, except the Floyd, has its headwaters on the west slope of the divide.

Again, Little Sioux river and its tributaries present exceptions. It drains the west side of the Mississippi-Missouri divide in the reëntrant between Storm Lake and Worthington, Minnesota, a distance of about 125 miles, and for most of this distance runs parallel with the divide. Its upper course is southward across Dickinson and northern Clay counties. At Spencer it changes direction and flows east for four miles to the mouth of the Dickens outlet, thence south to Gillett Grove, from that point southwest to Sioux Rapids, and thence west and north of west to the southeast corner of O'Brien county. Here it changes to a direction southwest by south and follows this course to the Missouri river (Plate XIX).

Ocheyedan river flows southeast across eastern Osceola and northwestern Clay counties to its union with the Little Sioux at Spencer. With its tributary, the Little Ocheyedan, it drains, by streams leading to the southeast, the east slope of the high north-south watershed of central Osceola county. Stony creek in southwestern Dickinson and northwestern Clay counties also has a course east of south. Willow creek in southwestern Clay county flows east by southeast to Little Sioux river. Waterman creek, which drains the east slope of the high watershed of eastern O'Brien county, flows east of south to its union with the Little Sioux. All these western tributaries of the Little Sioux, as well as the Little Sioux itself above the bend east of Spencer have courses leading southeast, which would fit the Mississippi drainage better than that to which they now belong. Southwest of the northeast corner of Cherokee county, the course of the Little Sioux is typical for the streams of western Iowa. Between the bend east of Spencer and northeastern Cherokee county, the course of the Little Sioux is characteristic of neither system, but appears to be accidental. Judged by the pattern of drainage, the high watershed of O'Brien and Osceola counties fits better as the great watershed of the state than the present divide along the moraine of western Palo Alto and Emmet counties.

As a result of the peculiar course of the Little Sioux with respect to its western tributaries, some very indirect water routes exist. Where the Little Sioux leaves the southwest corner of Clay county, it is only nine miles from the headwaters of Willow creek, although it is more than fifty miles by the route the water follows. The distance between the Ocheyedan valley in northeastern O'Brien and the Little Sioux valley in southeastern O'Brien is only twenty-one miles, but the water route is eighteen miles eastward into Clay county and follows an irregular course of more than sixty miles.

Conclusions.—The course of the divide northwest of Storm lake has now been tested in three ways: The position or directness of the course, the altitude, and the pattern of drainage. All these lines of evidence indicate strongly that the true Mississippi-Missouri divide north of Alta should continue west of north through O'Brien and Osceola counties along the west side of the Little Sioux drainage basin north of northeastern Cherokee county, and that the region drained by the Little Sioux and all its tributaries above northeastern Cherokee county, once was drained southeastward by way of Des Moines river to the Mississippi.

Possible Pre-Wisconsin Stream Courses and the Successive Drainage Changes.—If this conclusion is accepted the questions at once arise, what were the courses followed by these streams in pre-Wisconsin time, and what were the successive changes, with their causes, that brought about the present drainage.

The Little Sioux drainage system above Spencer consists of two principal streams, the Ocheyedan and the Little Sioux proper. Above their union the Ocheyedan river is longer than the Little Sioux, and below their union at Spencer, they continue eastward for four miles in a course which is the direct continuation of the Ocheyedan valley, and this course is then continued farther eastward by the Dickens outlet which enters the Little Sioux at its southward bend. It seems therefore that the Ocheyedan should be considered the headwaters of the system. Professor Macbride inferred[41] that the pre-Wisconsin course of the Ocheyedan was eastward up the Dickens outlet past Ruthven to the Des Moines river and carried with it the drainage of the present Little Sioux system above its southward bend east of Spencer. This interpretation probably is correct, and some of the low marshy areas of eastern Freeman township, as in sections 27, 26 and 24, and Elbow lake south of Ruthven may mark parts of this course.

The small creek draining southwestern Sioux township was part of this eastward drainage, and another tributary probably headed southward along the course of the present Little Sioux valley toward Gillett Grove, and received as part of its drainage the creek which drains the central part of Gillett Grove township. This latter creek and others of the adjoining sections now join the Little Sioux with an acute angle down stream. The bend east of Spencer apparently was caused by the damming of the eastward flowing stream (pre-Wisconsin Ocheyedan) by the Wisconsin ice-front. The ponded waters then ascended the valley which headed southward toward Gillett Grove, and broke over to another valley leading southward.

A short distance below its southward bend at the mouth of the Dickens outlet, the Little Sioux valley is narrower and deeper and the sides are steeper. At Gillett Grove the valley reaches the Wisconsin drift-boundary, and from here southwest to Linn Grove it follows this boundary. Throughout southeastern and southern Clay, northern Buena Vista and southwestern

[41]Iowa Geol. Survey, Vol. XII, p. 334, 1901.

O'Brien counties, the valley is narrow and deep, and the valley sides rise steeply to the level of the upland plain, 100 to 125 feet above the river (figure 38). This course apparently was established during the Wisconsin epoch, but the courses of the various pre-Wisconsin valleys which are represented in this valley, are only partly known. The successive damming of eastward flowing streams, with the resultant ponding and breaking over to more southerly and westerly valleys, would, could we but read it correctly, be an interesting and instructive record of events.

FIG. 38. Looking north across the Little Sioux river valley at Sioux Rapids. In the background are shown the steep bluffs and the even sky line formed by the edge of the Kansan drift-plain. (Macbride, Iowa Geological Survey, volume XI, p. 481.)

Within the Wisconsin drift of southeastern Clay county there are several long marshy depressions, some of which probably were pre-Wisconsin valleys, while others were made during the Wisconsin epoch. The valley of Elk creek in Logan township may be a pre-Wisconsin valley. Its course and characters were described on page 267. A slough almost half a mile wide and more than two miles long, with a direction west of north lies southwest of Webb in western Garfield township, and is continued to the north through Herdland township by a valley which opens into the Little Sioux. This is probably the course of a pre-Wisconsin valley. From the south end of this slough, another leads west across the north part of section 31, Garfield township, and the north part of section 36, Herdland township, and a valley continues this course west through sections 35 and 27 to the Little Sioux.

Willow creek enters the Little Sioux valley from the west in western Herdland township. In pre-Wisconsin time this creek probably flowed southeast along the present Little Sioux valley to section 27, and then eastward across sections 27, 35 and 36, Herdland township, and 31, Garfield township, by the low course noted above. This was apparently the chief stream of southern Clay county. Its course probably continued southeastward across Pocahontas county to Des Moines river, although it is possible that it may have turned southward to the headwaters of the Raccoon river. Another possible course for the pre-Wisconsin Willow creek is northeast along the present course of the Little Sioux to Gillett Grove, and thence by way of Elk creek valley eastward through Logan township toward the Des Moines river. This would account for the position of the Little Sioux valley from Gillett Grove to the mouth of Willow creek, as well as of Elk creek valley through Logan township, but it is not so plausible a course as that which continues the present direction of Willow creek south by southeast.

The present course of the Little Sioux valley westward along the north line of Buena Vista county and through the southwest corner of Clay county, probably is composed of parts of several older valleys; but it may have been largely one valley similar to the present Willow creek valley, which it parallels closely. A valley now enters the Little Sioux from the east at the bend of the river east of Sioux Rapids, and is followed by the Chicago and North Western railway from its head in the glacial marshes toward Marathon, down to the Little Sioux. A pre-Wisconsin stream in the Little Sioux course to the west may have flowed eastward along the course of this valley. Other small creeks entering the Little Sioux in sections 12 and 11 of Barnes township and section 13 of Brooke township may mark the southeastward continuation of courses of pre-Wisconsin streams which followed parts of the present Little Sioux course.

It is, however, not necessary to assume that there were pre-Wisconsin valleys along all this course of the Little Sioux. From Gillett Grove to Linn Grove its course is along the Wisconsin drift-margin, and since the general slope of southern Clay county is to the southeast, the waters obstructed in their natural course may have followed the edge of the ice and so determined the location of the valley. Where the drainage did not follow the ice-front, low passes may have determined the path from one drainage basin to another.

In pre-Wisconsin time Brooke creek was on the east side of the great watershed. Its upper part probably drained to the south and then passed eastward across Washington township to Raccoon river, and possibly the entire drainage course was reversed. When this valley, probably in section 21 of Washington township, was closed by the Wisconsin ice, the water was ponded and broke over to the north along the ice-margin, and then with the greater ponded areas from the northeast, broke across the great watershed along the present course of the Little Sioux.

The pre-Wisconsin Waterman creek might have belonged to either the Mississippi or the Missouri drainage. Its course through eastern O'Brien county has a direction a little east of south, and is reasonably direct as a continuation of the Little Sioux valley to the southwest. It would also have been well in accord with the Mississippi drainage pattern had it turned eastward at its present mouth, and followed the course of the Little Sioux past Peterson. A similar bend is made by the Ocheyedan river in northwestern Clay county. Farther to the southeast the course of this stream may have been eastward along the Little Sioux valley of northern Buena Vista county, or more probably southward by way of Brooke creek valley and eastward across Washington township, to Raccoon river. This interpretation would extend the headwaters of the pre-Wisconsin Raccoon to the north line of O'Brien county, making it a much longer stream than it is at present.

If Waterman creek flowed southwest to the Missouri system, the great watershed crossed the course of the present Little Sioux valley near Peterson, and continued northward along the divide east of Waterman creek to northeastern O'Brien county and then passed around the headwaters of Waterman creek to the high divide of southern Osceola county. If Waterman creek flowed southeast to the Mississippi system, the great watershed crossed the present course of the Little Sioux near the O'Brien-Cherokee county line, and continued northward along the divide west of Waterman creek to the high divide of southern Osceola county. The altitude of the divide to the west of Waterman creek is seventy to a hundred feet higher than the divide to the east, and its course is more direct. However, the Little Sioux valley at Peterson is narrowed and has more the appearance of being a cut across a divide, than has the valley at the north line of Cherokee county. Also the pre-Wisconsin gravel benches high up on slopes of Waterman creek valley seem to pass into the similar benches in the Little Sioux valley to the southwest, as if these valleys were continuous at the time the gravel was deposited. The evidence does not justify a positive statement and there is really little choice between the two possible courses, but the writer believes that the watershed east of the Waterman, although lower, was the Mississippi-Missouri divide.

DRAINAGE CHANGES IN THE BOYER RIVER BASIN.

A few miles south of Alta the Mississippi-Missouri divide extends in an east-west direction for six miles along the ridge between the headwaters of Boyer river and the Storm lake basin. Thence it extends to the south along the divide east of Boyer river to Wall lake outlet in southern Sac county. This offset is not great, but still the divide to the west of Boyer river is the more direct southward continuation through Sac county of the high watershed of western Buena Vista county. Also the altitude of the divide west of Boyer river is fifty to eighty feet higher than the present Mississippi-Missouri divide to the east (Plate XX, profile E). The altitude decreases southward from 1509 feet above sea level at Alta, to 1440 feet where it is crossed by the Chicago and North Western railway a mile east of Schaller, and to 1400 feet east of Odebolt.

The pattern of drainage on opposite sides of the Mississippi-Missouri divide through Sac county is the same, with Indian creek on the east and Boyer river on the west following parallel courses, east of south. Both are typical of the drainage to the east. The pattern on opposite sides of the divide west of the Boyer is different. The Boyer heads on the east slope of the great watershed, in southern Buena Vista county, and flows almost parallel with it, in a direction east of south, for more than twenty miles to southern Sac county, while on the west slope in this same distance, six different creeks, tributaries of the Maple river, have their headwaters normal to the course of the watershed.

Judged by the position or direction of its course, its altitude, and the pattern of drainage, the divide west of Boyer river was the great watershed as far south as southern Sac county.

In Levey township west of the town of Wall Lake, the Boyer river changes its direction from east of south, to southwest and flows in a direct course to Missouri river. Above this bend the Boyer flows through a broad open valley with gentle slopes Southwest of the bend it enters a narrow steep-sided valley that cuts through a high, rugged region which connects the high watershed west of the upper Boyer with the watershed, which, beginning in the northwest corner of Carroll county, continues southeast across southern Iowa, as both the highest watershed and the Mississippi-Missouri divide. Leading eastward from the bend is the abandoned Wall lake outlet (page 256), which crosses the Mississippi-Missouri divide and opens out on the Wisconsin drift-plain. This abandoned valley is wider and has gentler slopes than that now followed by Boyer river to the southwest. In pre-Wisconsin time the Boyer river turned eastward and passed through the Wall Lake outlet toward Raccoon river. When the ice-edge blocked this eastward drainage the ponded waters in the valley broke over a low place in the great watershed near Herring, in southwestern Levey township, and escaped to Missouri river. This course was cut so low during ice-occupancy, and the old valley to the east was so much filled that the Boyer continued to flow to the southwest and did not again take its eastward course to the Raccoon.

CONCLUSIONS.

As a result of the Wisconsin glaciation the earlier drainage to the Mississippi was diverted westward over the divide at two places and both diversions became permanent, at the expense of the Mississippi drainage. As a result of the diversion to the Boyer valley southwest of Wall Lake, the divide from southern Sac county to southern Buena Vista county was shifted five to seven miles to the east, and the drainage basin of the Boyer was increased by about 150 square miles. The diversion to the Little Sioux valley was much greater, for the divide was shifted thirty to thirty-five miles to the east, and the drainage basin of the Little Sioux was increased by almost 2,000 square miles. Within our area the present Mississippi-Missouri divide is the same as during pre-Wisconsin times for only seven to eight miles to the north and south of Alta in southwestern Buena Vista county.

CHAPTER III

THE KANSAN DRIFT-REGION.

The Kansan drift-region of northwestern Iowa is the area west of the Wisconsin drift-boundary. It includes all of Lyon, Sioux, O'Brien, Plymouth, Cherokee, Woodbury and Ida counties and parts of Osceola, Dickinson, Clay, Buena Vista and Sac counties (Plate XV). To the south it broadens out into the great Kansan drift-region of southern Iowa and northern Missouri. Northward it continues into southwestern Minnesota and eastern South Dakota, occupying the narrow area between the Des Moines and the Dakota lobes of the Wisconsin drift-region. From the northwest corner of Iowa southward to Canton the Big Sioux valley forms the boundary, with the Dakota lobe of the Wisconsin drift-plain to the west. South of Canton, the Kansan plain extends westward into southeastern South Dakota and northeastern Nebraska.

The Kansan drift-region, as interpreted in this report, includes in its eastern part that questionable area of northwestern Iowa which has been variously interpreted as covered with Wisconsin, extra-morainic Wisconsin, Early Wisconsin, Iowan or Kansan drift. This region was left outside the Wisconsin drift-sheet when the boundary of that area was retraced in 1909 and was studied during parts of the field seasons of 1910 and 1911. Various lines of evidence indicated that the eastern part of the area here called Kansan, the questionable area noted above, should be assigned to another drift-region, of an age intermediate between the Kansan and the Wisconsin. However, a super-Kansan drift-sheet could not be separated at most places and the topography did not seem to afford a consistent boundary line. The conclusion was reached that all of northwestern Iowa west of the Wisconsin boundary was of Kansan age. It was on the basis of this conclusion that the "Map of Iowa Showing Drift Sheets" published with Volume XXI of the Iowa Geological Survey, on which, in northwestern Iowa, the Kansan drift is represented as extending eastward to the Wisconsin boundary, was prepared. This map is reproduced as Plate XIV of this volume.

The publication of this report has been deferred from time to time because of certain questions concerning the area included in the eastern part of the Kansan drift-region and because work was being done in other parts of Iowa by members of the Iowa Geological Survey, and in southwestern Minnesota by Mr. Frank Leverett of the United States Geological Survey which it was thought might aid in the solution of the problem. The writer studied this questionable area further in 1913 and in 1916. During this time several conferences were held in the field with Director Kay of the Iowa Geological Survey, Mr. Leverett of the United States Geological Survey, and Mr. Lees, Assistant State Geologist of Iowa. In 1913 a western boundary of this questionable area, which the writer tentatively called the Intermediate drift-region, was traced. It is a very indefinite boundary which crosses eastern Lyon, northeastern Sioux, southwestern O'Brien, eastern Cherokee, northeastern Ida and southwestern Sac counties. The recognition of this Intermediate area rested almost entirely on topography, as a continuous drift-sheet could not be established.

In 1916, the writer in company with Professor Kay, attempted to clear up the matter of the age of the Intermediate area.

A more detailed study of the loesslike clay that overlies the Intermediate area convinced the writer that it is the leached loess and the continuation of the loess of the Kansan region farther west. This correlation of the loesslike clay with the loess makes the area preloess in age. This correlation, coupled with the practical identity of the drifts of the Kansan and the so-called Intermediate areas, and the indefinite boundary separating the two areas, led the writer to re-affirm the interpretation made in 1911, that all of northwestern Iowa west of the Wisconsin boundary belongs to the Kansan drift-sheet. It is believed that the somewhat peculiar topography which exists over the northeast part of the area here called Kansan, and which is not like the typical topography of the Kansan farther southwest, must be explained in some other way than by assuming that it was overridden by another ice-sheet which modified the topography but which left no continuous drift sheet.

Topography.

GENERAL CHARACTERISTICS.

The Kansan drift-region presents considerable diversity of topography. In its northeastern part, in Osceola, Dickinson, O'Brien and Clay counties the topography is slightly rolling, with, in part, local relief of only twenty to thirty feet. To the west and southwest the relief and ruggedness are greater, so that a rolling topography characterizes most of Lyon, Sioux, Plymouth, Cherokee and western Buena Vista and Sac counties, and in Woodbury and Ida counties the topography is rugged with a relief of 125 to 150 feet. The relief and ruggedness are less also farther from the rivers and nearer the inter-stream areas. The region contains level or almost flat areas; areas with slight relief, with long, gentle slopes; areas of moderate relief, well drained; rolling and rough areas with steep slopes; and sharply dissected areas with very steep slopes. These various types of topography have an orderly arrangement with respect to the chief drainage lines and in most cases grade gradually one to another.

The entire surface of the Kansan drift is in slopes, mostly definite, but in some cases so gentle as to be almost imperceptible.

The entire surface is therefore drained, although in some places poorly so. The drainage is characterized by long, direct stream courses, which for any particular locality, generally have a rather uniform direction, but diverge enough to make a dendritic stream pattern. Long, gentle slopes lead down on either side, making a topography of broad, open valleys. The steepness of the slopes varies with the relief.

The topography of the Kansan drift-region is in the main an erosional topography and is in the mature stage of the erosion cycle. The more level areas, however, do not seem to represent the original Kansan plain as do the level uplands of southern Iowa, but the region seems rather to have been eroded beyond the mature stage of the cycle.

DESCRIPTION OF THE TOPOGRAPHY.

The Slightly Rolling Areas.—Most of Osceola, O'Brien and Clay counties outside the Wisconsin drift-boundary have a topography that is only slightly rolling with areas that are almost level on the broader of the interstream spaces. A view of one of these level areas in northeastern O'Brien county is shown in figure 39. The largest of these level areas is found in western Clay county, in Lincoln, Clay and Lone Tree townships, between Willow creek and Ocheyedan river. The surface is so level that the natural drainage is poor, but there is sufficient slope for successful tiling and this is now a very productive farming region. Most of western Clay county within the Ocheyedan-Little Sioux loop has a slightly rolling topography, and at many places this comes to the very edge of the Little Sioux valley and with its gentle slopes is in decided contrast with the deep, narrow valley of the Little Sioux (figure 38).

Another fairly level area of considerable size is present along the Osceola-O'Brien county line between Melvin and Plessis, and smaller areas exist in northcentral Goewey, southeastern East Holman and southcentral West Holman townships of Osceola county, and in the westcentral and southwestern part of Lincoln township, O'Brien county. From the large area of slightly rolling topography of northern O'Brien county, narrowing areas extend southward along the divides between Floyd river and

FIG. 39. View across a level area of the Kansan drift-plain northwest of Hartley in northeastern O'Brien county. (Photo by Lees.)

Mill creek valleys, and between the valleys of Mill and Waterman creeks.

A very level area lies just south of the Wisconsin drift-boundary of southwestern Dickinson and southeastern Osceola counties, and similar though smaller areas are found east of Little Sioux river from Milford to Dickens and to Gillett Grove. The evenness of some of these areas may have been accentuated by the outwash from the Wisconsin ice-front (pages 267 and 272), but they apparently were very level before the Wisconsin epoch.

North of Spencer in the adjoining corners of Sioux, Meadow and Summit townships is another very level area, probably the flattest surface of the Kansan drift-plain. It is but little above the Little Sioux valley to the southwest, and is so level as to be poorly drained. The poor drainage of this district is due partly to a low ridgelike belt of sand hills along the edge of the Little Sioux flat, which has obstructed the drainage from the north (page 331).

Within this slightly rolling area of Osceola, O'Brien and Clay counties there are more strongly rolling belts along most of the larger valleys. These broaden southward along the valleys until the intervening, slightly rolling areas are entirely eliminated. Along some of the valleys, as the Little Sioux below Gillett Grove and the Waterman, a sharply dissected topography exists.

The Rolling Areas.—West and southwest of the slightly rolling area is a region that is characterized by rolling topography but which includes small patches of slightly rolling topography. This area without definite boundaries includes most of Lyon and Sioux counties, eastern Plymouth, Cherokee, and western Buena Vista and Sac counties. As noted above, prongs of this rolling topography extend northeast up the valleys into the region of slightly rolling topography and in turn prongs of the rugged topography to the southwest extend up the valleys into this area. On the intersteam spaces there are areas of slightly rolling topography. Such areas are found around Marcus in northwestern Cherokee county and northwest of Boyden in northern Sioux county.

The relief of this area may be as small as thirty to fifty feet or as great as a hundred feet or more. The drainage pattern is distinctly dendritic, the slopes are definite and the region is well drained. This area includes the best farm land of northwestern Iowa.

This area and that to the northeast have at many places small features that appear to be constructional. They are located on surfaces of more distinct erosional features, giving to the slopes a somewhat uneven or billowy appearance. These features suggest that a later ice-sheet overrode the region at a time when it had an erosional topography and left a thin but uneven veneer of drift. Such an explanation was carefully considered during the progress of the field work. It was not possible, however, to differentiate a drift material or find a definite southwest boundary for these apparently constructional features. The more prominent features are gravel hills on the Kansan drift (pages 362 to 372), and the billowy appearance of the surfaces of the erosional features is apparently due to an uneven mantle of loess which overlies the erosional surface (page 343).

The Rugged Areas.—Southwest of the rolling area the topography becomes more strongly rolling and passes into what may be called rough or rugged. This district includes a belt which widens southward along the Big Sioux in Lyon, Sioux and Plymouth counties (figure 40), and embraces all of Woodbury, all of Ida except the northeast corner, and the southwest corner of Sac county. This area has a topography like the typical Kansan of southern Iowa with which it is continuous southward.

FIG. 40. View of the Kansan drift topography along Broken Kettle creek in western Plymouth county. (Bain, Iowa Geological Survey, volume VIII, p. 321.)

The general relief of this region is 100 to 150 feet and the slopes are steep, but on some of the divides there are small areas of only moderately or slightly rolling topography. Such an area exists around Holstein in northern Ida county.

An area just east of the Missouri river valley in Woodbury and southwestern Plymouth counties has a topography of a bold, rugged type, characterized by steep slopes which are at many places almost bare of vegetation, by pointed hills, and by narrow ridges (figure 41). This belt has a thick deposit of loess and the topography is partly loess-formed. Five to ten miles from the river flats, with the decrease in the thickness of the loess, this topography grades into the more typical erosion topography of the Kansan drift-region.

Aggraded Areas.—At several places within the Kansan region, there are almost level areas that have been formed by the filling in of low areas with gravel. A good example is found west of

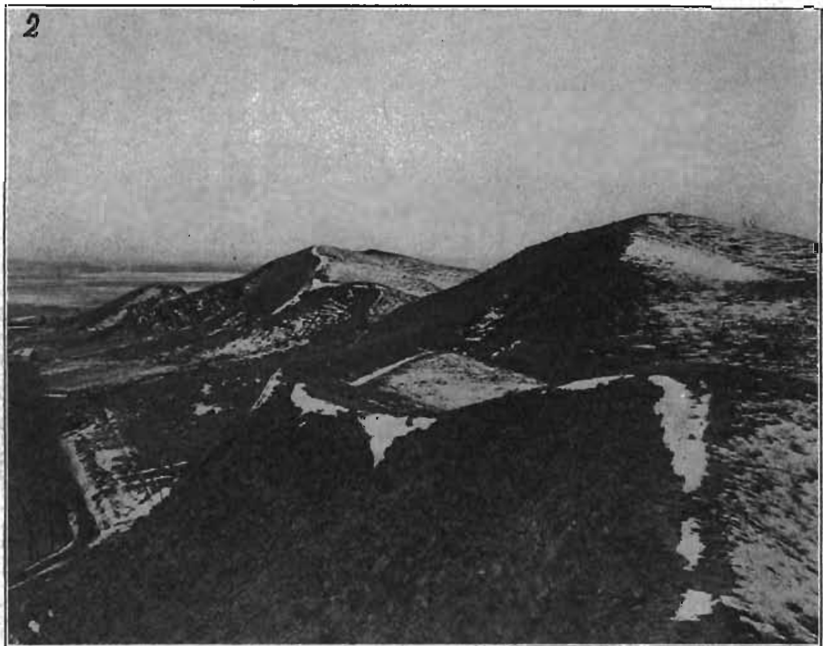


FIG. 41. The topography of the loess-covered region north of Turin, Monona county. Snow partly covers the surface. (Shimek, Iowa Geological Survey, volume XX, p. 289.)

Primghar in central O'Brien county, where several branches of Mill creek unite (page 403). Here a level area several square miles in extent is almost wholly underlain with gravel. Another lies east and southeast of Sibley in East Holman township, Osceola county, where areas extending some distance back from the present valleys are underlain with gravel (page 386).

Sharply Dissected Areas Along Valleys.—Along some of the larger valleys of the Kansan drift-region there are areas characterized by sharp dissection and considerable local relief, giving a very rugged topography along the valleys, although the inter-stream areas present rounded slopes and slight relief. This topography is found along the Little Sioux valley in Cherokee, southeastern O'Brien, and southern and eastern Clay counties. It exists also along the lower courses of the larger tributaries of the Little Sioux, as Mill, Waterman, Willow and Brooke creeks (figure 42). It has its greatest development in northeastern Cherokee and southeastern O'Brien counties, where Little Sioux

FIG. 42. View showing the rugged topography in the lower course of Brooke creek in northwestern Buena Vista county. This topography is typical of the lower courses of the larger tributaries of Little Sioux river. (Macbride, Iowa Geological Survey, volume XII, p. 315.)

river is 175 to 200 feet below the upland, and where many small tributaries have cut three to five miles into the upland, producing a much dissected area with a relief of 125 to 150 feet. The slopes are steep but the divides are level and project as spurs of the upland between the ravines out to the very edge of the Little Sioux valley.

East of southeastern O'Brien county the sharply dissected belt along the Little Sioux valley is narrower, and at many places the slightly rolling plain comes up to the very edge of the valley. Good examples of this condition are to be found on either side of the valley in the southwest corner of Clay county, in Gillett Grove township of eastern Clay county, opposite Sioux Rapids (figure 38), and elsewhere. Notably sharply dissected areas are present southeast of Cornell in Herdland township, in section 4 of the same township, in section 27 of Peterson township and at other places.

The area of sharply dissected topography along the Little Sioux valley is more extensive at the mouths of the tributary creeks, and extends up the larger of these creeks for a number of miles. It extends several miles up Willow creek valley in southcentral Clay county but with decreasing relief and ruggedness. It continues up Brooke creek valley (figure 42) in northwestern Buena Vista county for about four miles, and up other smaller creeks to the northwest of Brooke creek through the northcentral part of Brooke township. In southeastern O'Brien county where this sharply dissected topography is so well developed along the Little Sioux, it continues up Waterman creek valley for seven to eight miles, through central Grant township. The dissection here is remarkably sharp, giving a topography that is in striking contrast with the level upland to the east and west. The sharply dissected topography extends six to eight miles up Mill creek valley in Cherokee county and affects the lower courses of its tributaries.

If they are viewed from a distance, most of these tributaries of the Little Sioux appear to have broad shallow valleys, but as they are approached more closely what appeared to be broad shallow valleys are found to be trenched by narrow steep-sided valleys (figure 43). This feature is particularly prominent in

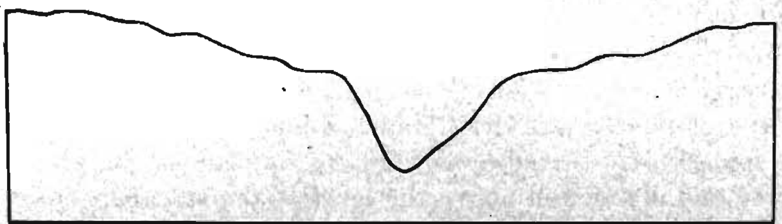


FIG. 43. Cross profile of a tributary valley of the Little Sioux showing the trenchlike inner valley cut into the broader outer valley.

the lower courses of the tributaries. Farther up these creeks, the narrow valleys in the bottoms of the older ones grow shallower until they terminate, and above their upper ends the streams flow through broad shallow valleys similar to the wider parts of the valleys farther down stream. The valley of a small creek which joins Mill creek in section 10 of Cherokee township and which is followed by the Illinois Central railway northward toward Larabee, shows well the passage from the sharply dissected topography to topography of the upland type. In its lower course the inner valley is sixty to seventy-five feet deep, but farther north it is shallower until at Larabee it is absent and farther northward the stream flows in a broad, shallow valley.

When the Ocheyedan-upper Little Sioux system was thrown southwestward across the great watershed into its present course (pages 310 to 318), new conditions were established and the great quantity of water carried by the Little Sioux soon deepened its valley notably, and destroyed the adjustment between it and its tributaries. The rejuvenated tributaries and the valley-side gullies then began to carve out the sharply dissected topography described above. It is all the work of post-Wisconsin time, and cutting in the tributary valleys is still in progress.

Gravel Hills.—At various places on the Kansan plain there are gravel hills or mounds hardly distinguishable from the usual features of the region. Some of them are in groups; some in rows along the upland valleys; and some are single isolated hills. In the northeast corner of Lyon county north and west of Little Rock there is a group of these hills which give a topography which appears to be constructional. Along the course of Willow creek leading west from Calumet in southern O'Brien county there is a row of them. These kamelike hills are more fully treated on pages 362 to 372.

Gravel Benches.—Gravel benches exist along many of the valleys of the Kansan drift-plain. Some of them are conspicuous topographic features, as they are continuous for great distances and stand well above the level of the streams; but some are merely inconspicuous remnants of terraces or shoulders on the valley sides. They are most prominent along the Little Sioux through Cherokee county and in the lower courses of Mill, Waterman and Brooke creeks. The dissection of the benches is as a rule much sharper than that of the uplands, being of the sharply dissected type of topography described above (pages 327 to 330). All the small creeks cross these gravel areas in narrow, steep-sided valleys while upstream on the upland they may have broad, open valleys. Even the smaller valleys generally have gravel deposits along their courses, even out near the heads of small streams on the upland. Benches may or may not be present, depending upon the extent to which the stream has cut into the valley filling. The valley gravels are discussed more fully in Chapter V.

Sand Hills North of the Spencer Flat.—At a number of places along the north side of the Spencer flat there is a topography characterized by low, rounded hills, with a relief of only ten to twenty feet. These hills appear at first sight to be glacial but a closer examination shows that they consist largely of sand, and that sandy roads are common in the belt where they are present. As noted on page 324 the poor drainage of the plain just north of Spencer apparently is due in part to obstruction caused by this low, ridgelike belt of hills.

This topography begins at the east end of the Spencer flat just west of Meadow brook, and extends westward as a low, slightly rolling ridge bordering the flat through the north half of section 9, the south half of section 5, and the central part of section 6 of Sioux township. It is present in section 1 of Riverton township and in the north half of section 36 and the northeast quarter of section 35 of Summit township where some shallow road-cuts show exposures of sand. The north half of section 32 and the adjoining parts of sections 29 and 30, Summit township, on the point of upland between the Little Sioux and Stony creek valleys, have a topography of slightly rolling hills with a relief of about ten feet, and the road on the north line of section 32 is quite sandy. Similar topography and sandy roads are found just north of Everly, and in section 33 and the southwest quarter of section 28 of Waterford township are rounded hills half a mile back from the valley which are said to be composed of sand. Farther northwest at the southeast corner of Osceola county, along the east bluff of the Ocheyedan river valley, there is another belt of low, rounded hills composed of sand, and similar features are shown faintly northwest for several miles across Harrison township.

The distribution of these sand areas to the north of the Spencer flat and to the northeast of the Ocheyedan valley accords with the usual location of eolian deposits on the northeast side of valleys, due to the prevailing southwest winds of our latitude. They probably were formed during the Wisconsin glacial epoch when Ocheyedan river was carrying great floods of debris-laden water from the margin of the Wisconsin ice-sheet.

All these areas of sand hills are along the course of the "Altamont moraine", as mapped by Professor Macbride in his discussion of "The Margin of the Wisconsin Drift"[42] (figure 28). They resemble a faint, glacial topography, and may have been so interpreted by Professor Macbride.

---

[42]Iowa Geol. Survey, Vol. XII, pp. 329 and 333, 1901.

HISTORY OF THE KANSAN TOPOGRAPHY.

In the Kansan drift-region of southern Iowa the principal divides of a region commonly rise to a uniform altitude and have some level surface at their summits. These level areas are interpreted as remnants of the original Kansan drift-plain which is thought to have been relatively level, without marked constructional features.

These level uplands of southern Iowa are covered with fifteen to twenty feet of gray to dark colored, noncalcareous, sticky clay which Professor Kay has called gumbotil[43] and interpreted to be the result chiefly, of the chemical weathering of Kansan drift[43a] on the level Kansan drift-plain. After the development of the gumbotil zone uplift is believed to have occurred and erosion has carved out a mature topography and reduced most of the surface below the level of the former gumbotil plain. The above interpretation is based on the evidence of the few remnants.

Remnants of the gumbotil zone have been found northward to Carroll and Crawford counties, just south of our region.[44] The most northerly known outlier of the Kansan gumbotil is exposed in a railway cut east of Kiron, a few miles south of the southwest corner of Sac county.

Neither the level uplands nor the gumbotil have been found within our region although exposures of unleached till have been seen on most of the high areas. However, it is believed that northwestern Iowa has passed through essentially the same history as has been outlined for southern Iowa by Professor Kay. That is, that the Kansan ice-sheet left a relatively even drift-plain; that the gumbotil was developed over the entire region; that the gumbotil plain was uplifted; and that it has since been eroded. This erosion, however, has been greater in northwestern Iowa than in southern Iowa, so that, although remnants of the plain and the gumbotil remain in southern Iowa, in northwestern Iowa all the surface has been reduced below the level

[43]Kay, G. F., Gumbotil, a New Term in Pleistocene Geology: Science, Vol. 44, pp. 637-638. 1916. See also this volume. p. 217.

[43a]Kay. G. F., Bulletin of Geol. Society of America, Vol. 27, pp. 115-117, 1916. Also Iowa Geol. Survey. Vol. XXV, pp. 612-615, 1916.

[44]Kay, G. F., Pleistocene Deposits between Manilla in Crawford County and Coon Rapids in Carroll County: Iowa Geol. Surv., Vol. XXVI, pp. 213 to 231, 1917.

of the gumbotil plain and every remnant of the plain and the gumbotil has been destroyed.

Concerning this matter of erosion of the gumbotil plain in Carroll county just to the south of our area Professor Kay says:[45]

> The history of northern Carroll county and farther to the north seems to have differed from the history of the Templeton region (southern Carroll county) in having undergone still greater erosion. Northward from Templeton there are fewer and fewer remnants of the weathered zones until none are found. Moreover, in the region of Templeton there appears to have been more erosion than farther to the south. In southcentral Iowa the uneroded remnants of upland with gumbotil and leached drift are a somewhat distinctive feature of the topography.

The above explanation includes several points that have not been conclusively proved but the interpretation explains the conditions fairly well. It has not been proved that the gumbotil plain extended over northwestern Iowa. However, the writer has seen some of the evidence, in southern Iowa and in Carroll and Crawford counties just south of our region, upon which Professor Kay bases the gumbotil idea, and considers it so strong that he cannot fail to use this interpretation for the southern part of the region here under discussion. It is believed that the development of the gumbotil to a depth of fifteen to twenty feet over southern Iowa required a very great length of time. Such thicknesses are found northward to Carroll county where a section recorded by Professor Kay from a railway cut three miles west of Templeton shows twenty and one-half feet of Kansan gumbotil.[45a] It seems very probable therefore that the gumbotil was developed farther northward over northwestern Iowa during this same long interval of time.

The way in which the remnants of the gumbotil on the highest divides become fewer and smaller as they are traced northward in westcentral Iowa, and especially in Carroll county, indicates

[45]Iowa Geol. Surv., Vol. XXVI, p. 218, 1917.
[45a]Iowa Geol. Survey, Vol. XXVI, p. 220, 1917.

strongly that these remnants have been entirely destroyed farther north, that is that northwestern Iowa has been entirely reduced below the level of the gumbotil plain. The altitude of the remnants of the gumbotil along the divide between Mississippi and Missouri rivers increases northward from about 1250 feet at Tingley near the south line of the state to nearly 1500 feet west of Templeton in Carroll county. If these altitudes are used to project the plain northward, it is found that it would pass above all the high points.

An uplift of the region is postulated in order to cause the erosion of the gumbotil plain. In southern Iowa where remnants of the gumbotil plain exist the postulated uplift rests on firmer basis than for northwestern Iowa, where the uplift is merely inferred. The question as to why northwestern Iowa was eroded more deeply than southern Iowa in spite of the fact that it is farther up the Missouri valley, has not been satisfactorily answered. Possibly the uplift in northwestern Iowa was greater than in southern Iowa; possibly it occurred earlier. There exist in northwestern Iowa considerable areas of slight relief which must be interpreted as having been reduced below the original plain and yet they are not at flood plain level. The origin of these areas is not understood.

The Kansan Drift.

GENERAL CHARACTERISTICS.

The Kansan till of northwestern Iowa consists of a clay matrix with numerous sand grains, pebbles and bowlders scattered through it. The matrix is finely ground rock-flour, gritty from the presence of very small sand grains, but somewhat plastic if moderately moist. At the surface and in exposures of moderate depth the till is oxidized and has a yellow or brownish yellow color. Below this is the unoxidized "blue clay" phase of the Kansan. The till is cut by numerous joint planes belonging to sets that intersect at such angles as to give the clay a very characteristic fracture into angular fragments a quarter to three-quarters of an inch across. Both the oxidized and unoxidized phases are strongly calcareous even up to the surface or up to the base of the overlying loess. Calcareous material is present further in the form of small grains, pebbles and bowlderets of limestone, and near the surface at many places, as small concretions and as gray powdery material along joints.

At many places within the Kansan region, a drift somewhat lighter in color than the typical Kansan is to be found. It is yellowish gray or brownish gray instead of the usual brownish yellow. However, the difference is not distinct and it seems that there are all gradations. Commonly this lighter colored till contains considerable pebbly material scattered through it and has associated with it lenses and beds of gravel. This phase of the till is found in a number of exposures north of Cherokee, as in the bluffs of Mill creek in section 14; as a layer of till in the pit of the Cherokee Sand and Gravel Company; and in the northwest quarter of section 13, Cherokee township, on the farm of M. Doupe. North of Cherokee county, this phase is commonly present and is the usual till material. The difference is not one that would distinguish this as a separate till and it is apparently a fresh phase of the Kansan where it is associated with and contains much gravel.

The yellow clay at the surface and on the face of cuts is moderately loose, but a few inches beneath the surface it is compact and hard, and if wet is tough and gummy. The oxidized yellow clay horizon has an average thickness of twenty to thirty feet, with a range from zero to probably fifty feet. In general, it is thicker in those parts having a more rugged topography and thinner in the more level regions. It is thicker on the hills than in the valleys, and in some of the marshy flats it is entirely absent, and blue clay lies directly beneath the soil or alluvium.

Calcareous concretions one to two inches across exist in the upper part of the oxidized Kansan till in many of the exposures. They are not so large as those of the Nebraskan till but are larger than those commonly found in the loess. They are formed by the leaching of calcium carbonate from the till and its concentration in nodules lower down in the drift. At a number of places these nodules have an elongate form and stand in a vertical position along the joint planes. They are more numerous and larger in the Kansan till south of our region, as exposed in the cuts of the Chicago, Milwaukee and St. Paul railway in Carroll county.

In most exposures the blue clay is plastic and gummy, and if only recently exposed, is very tough and hard. When dry it has a light, blue-black or bluish gray color on the face of the exposure, while just beneath the surface it is almost black, and with greater depth grades into the typical blue clay. The blue clay is exposed in the banks or beds of many valleys where erosion is now active, and is penetrated by all wells of any great depth. Its thickness varies with the total thickness of the Kansan, of which it forms the larger part.

The blue clay is the fresh unoxidized phase of the Kansan till, and the yellow clay is the oxidized form. The transition from the blue to the yellow is as a rule abrupt or accomplished within a very thin transition zone, but the alteration to a yellow color may extend down into the blue clay along joint planes, affecting the clay for several inches from these planes. Where the till is much broken by intersecting joints and is mixed with irregular pockets and veins of sand which allow the weathering agents irregular access to the till, there is, at the contact, a zone several feet thick made up of masses of unaltered till enclosed in altered till. Where the till is moist, and where, because of recent erosion and exposure, rapid alteration is now in progress, a blue-black phase is present in the transition zone between the blue and brownish yellow phases.

Gray limestone is the dominant rock material among the pebbles of the Kansan till, forming more than 70 per cent of the total number of pebbles. Other types of limestones, and a few quartzites and shale pebbles increase the number of sedimentary pebbles to about 77 per cent of the whole. The remaining 23 per cent are igneous pebbles, chiefly granites. The large bowlderets and bowlders are dominantly igneous; quartzite, which is never abundant in the analyses of pebbles, is common while limestone bowlders are rare. The pebbles of the Kansan drift are in most cases rounded or subangular, but a few are angular. The drift separates cleanly from the pebbles, and the white limestone pebbles show plainly against the darker clay.

SOURCE OF MATERIAL FOR THE DRIFT.

The bedrock of northwestern Iowa belongs to the Cretaceous system which also is present in great thickness to the north. The dominant rock of this system is shale, and the remainder is largely shaly limestone and friable sandstone. Its most notable contribution to the drift was the material for the clay matrix, which was derived largely from the shale, but it also yielded much soft limestone which was ground to powder. Although they contributed the bulk of the drift material, the Cretaceous rocks are not common among the pebbles, and never appear among the bowlders.

The compact, gray limestone pebbles of the till are commonly unfossiliferous, but a few contain fragments of Ordovician fossils. No limestone of this age is known in the bedrock of northwestern Iowa or for several hundred miles to the north along the course followed by the ice, but in the northwest corner of Minnesota and extending northward along the valley of Red River of the North through Manitoba to Lake Winnipeg and beyond, there is a belt of Ordovician, Silurian and Devonian rocks which probably furnish the limestone pebbles of our region. The igneous pebbles and bowlders were derived from the pre-Cambrian rocks of Canada and northern Minnesota, and from the smaller areas in the Red river and Minnesota river valleys. The large amount of calcareous material in the matrix of the drift was derived in part from the impure limestone and calcareous shale of the Cretaceous, and in part from the Paleozoic formations that furnished the limestone pebbles.

In the extreme northwest corner of Iowa are a few outcrops of quartzite, and to the northwest around Sioux Falls, there are considerable areas of this rock. It is very resistant, and furnished many bowlders for the drift of northwestern Iowa. In decreasing abundance they occur southward to the limit of glaciation.

Preceding the Kansan epoch, northwestern Iowa had been glaciated by the Nebraskan ice-sheet, which deposited a thick sheet of till. As the Kansan ice-sheet advanced over the surface of the Nebraskan till, it gathered up great quantities of the older till and mixed it with such new materials as it brought in, making the Kansan drift. It also picked up masses of Nebraskan till and incorporated them in the Kansan till without intimate mixing. There are also masses of gravel, sand and silt inclosed in the Kansan, and these probably were gathered in a similar way either from interglacial deposits resting on the Nebraskan, or from outwash deposits laid down in front of the advancing Kansan ice-sheet. These gravel masses and the evidence as to their age are considered on pages 357 to 361.

EXPLANATION OF THE FRESHNESS OF THE TILL.

A notable character of the Kansan till of northwestern Iowa is the small amount of alteration and weathering which it shows. Oxidation to a yellow color commonly extends to a depth of twenty to thirty feet, and locally the till is iron-stained along the joints, but the degree of this oxidation is only moderate. Excessive oxidation of the type represented by the iron-stained horizon (ferretto) present at the top of the Kansan till at many places farther south, is lacking in northwestern Iowa. Further, the Kansan till of northwestern Iowa is commonly calcareous to the surface. In only a few places, in the south and southwest part of the region, was any leached till found. Even where the overlying loess is leached for its entire thickness, the till beneath is unleached.

In southern Iowa leached till is much more commonly present and in many places has a depth of several feet. It occurs in a zone which directly underlies the gumbotil of the remnants of the upland, where it may be seven to ten feet thick. In such position it grades upward into the gumbotil and represents a less altered phase of the till.

If a gumbotil zone was formed over the Kansan drift-plain of northwestern Iowa, there was formed also beneath it a zone of leached till, but the erosion which removed every vestige of the gumbotil (page 332) also removed the leached zone of Kansan till beneath, exposing unleached till everywhere at the surface. This complete erosion of northwestern Iowa below the original plain explains the absence of leached till.

The Loess.

GENERAL CHARACTERISTICS AND DISTRIBUTION.

The Kansan drift of northwestern Iowa is covered with a mantle of fine-grained, yellow clay known as loess. In the southwestern part of the area the loess has a considerable thickness, but it thins to the northeast until it is almost negligible. In the regions where the loess is thick, it is commonly calcareous to the surface and in many exposures contains calcareous concretions and snail shells. Farther northeast where the surface is more even and the loess is thinner, it is leached in its upper part, and shells and calcareous concretions are absent.

The region within which a well developed loess covering exists includes Woodbury county, Ida county (except the northeast part), the southwest part of Sac county, and a belt along the east side of the Big Sioux valley narrowing northward through western Plymouth, Sioux and Lyon counties. Within this area many road-cuts on the slopes or on the crests of the hills expose ten to twenty feet of loess and commonly it is calcareous to the surface.

A particularly rugged belt five to ten miles wide just east of the Missouri river valley in Woodbury and southwestern Plymouth counties has a thick deposit of loess in which exposures of thirty to fifty feet or more exist. It is an area of distinctively loess-formed topography which continues southward along Missouri river across western Iowa (figure 41, page 327).

The loess is much thinner within a short distance to the northeast so that there appears to be a loess-boundary. This belt within which the loess becomes so much thinner leaves the Wisconsin drift-boundary near the south line of Sac county and extends northwest across southwestern Sac, northeastern Ida, southwestern Cherokee and southeastern Plymouth counties. West of the Floyd river valley it extends west of north through western Plymouth, Sioux and Lyon counties. The change is more abrupt in Sac and Ida counties than farther northwest and more abrupt where this belt follows valleys than where it crosses upland country. In some places it seems to be a definite boundary but on the whole it is simply a zone within which the thinning of the loess is very marked.

The zone within which the loess thins so notably is quite definite south of Wall Lake in Sac county through sections 33, 32 and 30 of Viola township and sections 25 and 24 of Levey township. To the southwest is a rough topography with a relief of fifty to a hundred feet and road-cuts at the crests of the hills show ten feet or more of loess. To the northeast the region is not so rugged, the relief is less and the mantle of loess is only a few feet thick. A marked contrast exists along a small valley through sections 33 and 32 of Clinton township northwest of Wall Lake. In section 32 on the southwest of this valley the topography is rugged with a relief of seventy-five to a hundred feet, with very steep slopes and sharp crests and the road-cuts through these crests expose fifteen to twenty feet of loess without reaching its base. Across the valley in section 33, the general altitude is thirty to fifty feet lower, the surface is moderately rolling and loess is not prominent. A similar contrast exists along the Boyer valley in sections 34 of Clinton and 2 of Levey townships. This latter case is directly east of the former and shows a repetition in an east-west line of the contrasting, opposite sides of the valleys.

Northwest of Odebolt toward Maple river there are several places where the border of the thicker loess is definite but it is not a continuous boundary. The loess is thickest on the higher points and there is commonly some group of hills or a divide where the thicker loess projects farther northeast than is general and along the northeast base of these hills the marked change is located. The first course of this type northwest of Odebolt is along the northeast base of a belt of hills in sections 21, 20 and 18. In section 18 this belt is cut across by a tributary of Odebolt creek but on the west the loess-covered hills continue through Blain township as the divide between Odebolt and Elk creeks. Loess-covered hills, however, exist north of Elk creek along the divide separating it from Buffalo creek in southern Silver Creek township, in section 26 on the headwaters of Buffalo and Elk creeks and in southeastern Logan township in the angle between Buffalo creek and Maple river. In the two latter places very marked contrasts exist for short distances.

A very marked contrast exists along the course of Maple river valley from section 25 of Logan township north to section 22 of Galva township. Rugged topography with deep loess cuts exists to the west of the valley while to the east it is less rugged and there are few exposures of loess.

Northwest of Maple river the loess thins more gradually, but at a number of places along the north-south valleys more rugged topography exists on the west slope than on the east. This feature is present in the case of several of the parallel valleys and is not a characteristic simply of the belt within which the loess becomes thinner but of the region of thick loess. This feature is shown along the West Floyd and other valleys of westcentral Plymouth county.

In the region farther northeast the loess exists as a thinner mantle commonly three to six feet in thickness. The slopes are gentle and exposures are few and shallow. Here the loess is leached in its upper part and at many places for its entire thickness where this is less than five feet. Where the loess is thicker than four to five feet, the basal part is unleached. The underlying till is commonly unleached even where the loess is entirely leached, which indicates that the leaching of the till takes place much more slowly than the leaching of the loess. The contact of the loess and the till is commonly definite even though the till surface has slight irregularities into which the loess fits.

This area within which the loess has a moderate thickness includes northwestern Sac, western Buena Vista, Cherokee, O'Brien and Osceola counties, outside the Wisconsin drift-boundary, and most of Sioux and Lyon counties. Most of this region has only a moderate relief and exposures are few.The natural exposures, being on the lower slopes of the valleys, do not commonly show the loess, which has been removed from such positions, and one must depend largely on artificial exposures on the level surfaces for data as to its thickness. Such exposures were found at Wall Lake, Odebolt, Arthur, Early, Schaller, Galva, Storm Lake, Alta, Cherokee, Primghar, Sheldon, Sibley, Little Rock and George (pages 349 to 356).

In Clay and southern Dickinson counties the loess is only two to three feet thick and the surface is very level. When it is less than two and one-half feet thick this mantle is commonly not definite loess but a loesslike clay which may contain sand grains and pebbles throughout. When traced from the southwest it is very evident that this is the continuation of the loess mantle.

TOPOGRAPHIC INFLUENCE OF THE LOESS.

The topography of the Kansan region is a loess-mantled topography. The influence of this mantle differs from place to place with the thickness of the loess and the nature of the topography at the time the loess was deposited. In the rugged belt east of Missouri river in Woodbury and southwestern Plymouth counties, the thick deposit of loess of the hill tops has been a dominant factor in the production of this topography. The topography in its character and its relief is, in part loess-formed. Throughout the remainder of the rugged region the loess is thickest on the hill tops, which results in a slight increase in the relief of the region.

Over the major part of our region the preloess topography was rolling or slightly rolling with a relief of thirty to sixty feet. The loess accumulated to a thickness of five to fifteen feet and made a somewhat uneven veneer which resulted in the formation of faint constructional features on the slopes of the major erosional features. It is in this region that the loess produced probably the greatest changes. Its effect was, in general, to make the slopes more gentle and in some places it entirely effaced small irregularities by filling in small valleys (page 352).

Far to the northeast where the surface was very even and the loess mantle deposited was thin, the topographic effect was slight, although here the effect was to make the surface more even by the filling of small irregularities.

THE LOESS OF THE KANSAN REGION.

The very definite and characteristic loess of the southwestern counties of our area has been recognized as loess from the earliest geologic work done in the region. This includes the area noted above (page 339) as having a thick covering of loess. The deposit that overlies much of the Kansan region to the northeast and which is commonly leached for its entire thickness has not previously been recognized as loess. It was called loesslike clay or loam by the writer through much of the progress of the work and its identity with the loess to the southwest was not demonstrated until the summer of 1916. Previous to this time there had been considerable question as to whether the whole of this region should be included in the Kansan.

The extremes included within the Kansan region are very different. In the region of thicker loess, the yellow calcareous concretion bearing fossiliferous loess is seen at many places. In the region of thinner loess, there are few exposures and these show the noncalcareous brownish yellow pebbleless loesslike clay. But within the region of positive loess there are exposures in which the upper part of the loess is leached and certain level areas where the leached loess is general, and in these places the leached loess is identical with the loesslike clay (leached loess) farther northeast. Scores of exposures were studied by the writer as he passed back and forth from the region of thick loess to that of thin loess and in this way the identity of the loess of the entire region was established. The loesslike clay of the thinly mantled areas is identical in origin with the distinctive loess of more deeply covered areas.

PEBBLES WITHIN AND ON THE SURFACE OF THE LOESS.

In the region of thin loess and to a large extent elsewhere a few pebbles may be found within the loess, especially in its basal part. Their distribution is of two types: (1) pebble bands bedded in the loess, and (2) occasional pebbles scattered through the loess. Those of the first class are restricted to the basal twelve to eighteen inches of the deposit and are found where the loess overlies gravel in the valleys, or on the lower slopes of the hills, where the loess accumulated on a topography of some relief. In the case of the occasional pebbles scattered through the loess they are found in large part where the entire thickness of the loess is not more than three feet. It was found that many of these pebbles could be shown to occupy old burrows of animals, and in many cases where the burrow was not at first apparent a careful examination revealed it. Not every pebble found in the loess was proved to be in a burrow but a large percentage of them was found to be so located and probably practically all have had such an origin. The burrows go from four to six feet beneath the surface and at some places are quite numerous. In some cases where the burrows passed through the loess into gravel below, the burrows appeared like tubes of pebbles in the loess. Where the loess is more than four feet thick few of the burrows go through the loess and there is no opportunity for obtaining the pebbles.

In almost any part of the loess-covered area it is possible to find a few pebbles on the surface or in the loess soil. They may be found along the public roads and less frequently in the fields. Careful search along the road enabled the writer to find one or more pebbles along practically every quarter of a mile of road where the search was made within the loess area. There are several ways by which these pebbles may have come to their present location. Where the loess is thin they may be brought up by burrowing animals from the drift beneath the loess. Many of the pebbles along the roads have dropped from the loads of gravel being hauled along these roads. The pebbles in the fields may come with manure hauled from barn lots, most of which have gravel in them. Others may have been carried from neighboring valleys in the mud attached to wheels, or to the feet of animals of historic or prehistoric times. It may be noted that during a search for pebbles, especially along the roads, one also finds nails, pieces of coal, cinders, iron, glass and crockery, bottle caps, bases of shot gun shells, etc. All these things have come to their present location by accident and were not derived from the loess beneath and likewise the few pebbles are believed to have come by accident to their position on the surface of the loess and not from within the loess.

Over much of the Kansan region the loess does not completely cover the surface but exists where conditions were favorable for accumulation or where erosion has been slight. The mantle of loess completely conceals the till where the surface is level or only slightly rolling, but on steep slopes the till is commonly exposed because erosion has removed the loess. The east and north slopes of hills have a thicker loess mantle than the opposite slopes or the crests of the hills, which is explained by the prevailing west and southwest winds and by the greater accumulation of the loess in the lee of the hills. Till is exposed at the crests or on the upper slopes of many hills which farther down the slopes have a complete loess covering. Under these conditions pebbles from the drift near the crest of the hill are washed down the slope onto the loess. Many examples of this condition were observed, where in ascending a loess-covered slope occasional pebbles were found and at the top of the slope the drift is exposed. It is not possible in all cases to show that the loess is above the till, but it is possible to do this at many places. An example of this is to be found west of Le Mars in Plymouth county west of West Floyd river on the south line of section 12, Washington township. Cuts in the lower slope show six to eight feet of loess without exposing the till but occasional pebbles are found on the road and in the gutters. Toward the crest of the hill just west of the southwest corner of section 12 the loess thins out and the till rises to the surface.

An excellent exposure showing the relation of the till and loess exists in a road-cut about fifty yards north of the southwest corner of the section 12 noted above. The cut extends from north to south, and is at the crest of a slope leading down to a valley to the north. The road grade ascends the slope and cuts the crest. At the crest of the hill the Kansan till rises five feet above the base of the cut and is overlain by six feet of brownish pebbly leached material (figure 44). In either direction from the crest the upper contact of the Kansan dips steeply and passes below the road grade, and the brownish leached zone thins to one foot and becomes an old soil. There is no true loess in the section at the crest of the hill, but below the crest in either direction it is present above the leached ma-

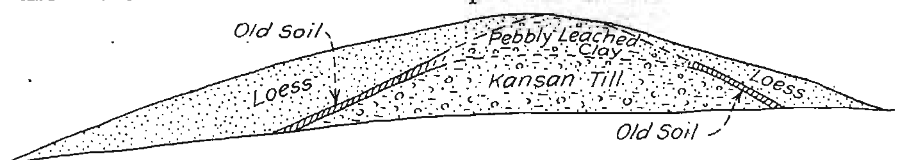


FIG. 44. Sketch of a road-cut exposure fifty yards north of the southwest corner of section 12, Washington township, Plymouth county.

terial and it thickens notably down the slopes, especially on the north slope where it attains a thickness of at least ten feet. Pebbles may be found lying on the loess on the natural slope of the hill and no doubt they were washed down from the leached pebbly material exposed at the crest of the hill. If this were a shallow cut it would be like scores of others which were seen but in which the source of the pebbles was not so evident.

The most indefinite part of the loess mantle is commonly found near the crests of the hills where the mantle is thin. It cannot in all cases be so definitely related to the till as in the exposure just described, for if the cut is shallow, the relation of this material to the loess is not evident and it may appear to be above the loess which covers the slope lower down. In all cases, however, where an adequate cut exists it is evident that the sandy, pebbly material passes below the loess or grades laterally into it. In no place does it overlie the loess. This material at the crests may be distinctly different from the loess, as in the cut described above, or it may differ from the loess only in the presence of a few pebbles. In the former case it has been derived in part from the till while in the latter case the bringing in of a few pebbles by burrowing animals or other means would suffice to explain the difference.

The description of some cuts along the road leading east from Cherokee will illustrate these relations. The north side of the road-cut about half way up the east slope of the Little Sioux valley exposed the following section, which is shown diagrammatically in figure 45 while a view of it is given in figure 46.

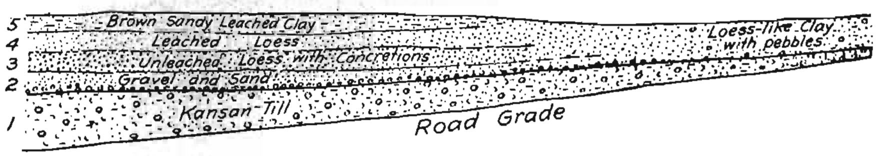


FIG. 45. Sketch of exposure showing the thinning of the loess toward the crest of a slope, and its passage into an indefinite pebbly loesslike clay. The exposure is in a road-cut in the east slope of the Little Sioux valley east of Cherokee. A view of a part of this exposure is given in figure 46.

		FEET.
5.	Slightly sandy dark material, including the soil......	2
4.	Leached loess	3
	In part of exposure it is very dry and hard and breaks out in blocklike chunks.	

3.	Ashy gray calcareous loesslike clay with concretions and containing some thin beds of sand at the base....	2½
2.	Sand and fine gravel with a few bowlders at the base.	2½
1.	Dark brown Kansan till, exposed....................	8

Number 5 of this section is slope wash material to which is added probably some sand blown up from the valley bench which is present lower down on the slope. Farther up the slope all horizons above the Kansan are thinner and numbers 3 and 5 pinch out entirely (figure 46). Near the crest the combined

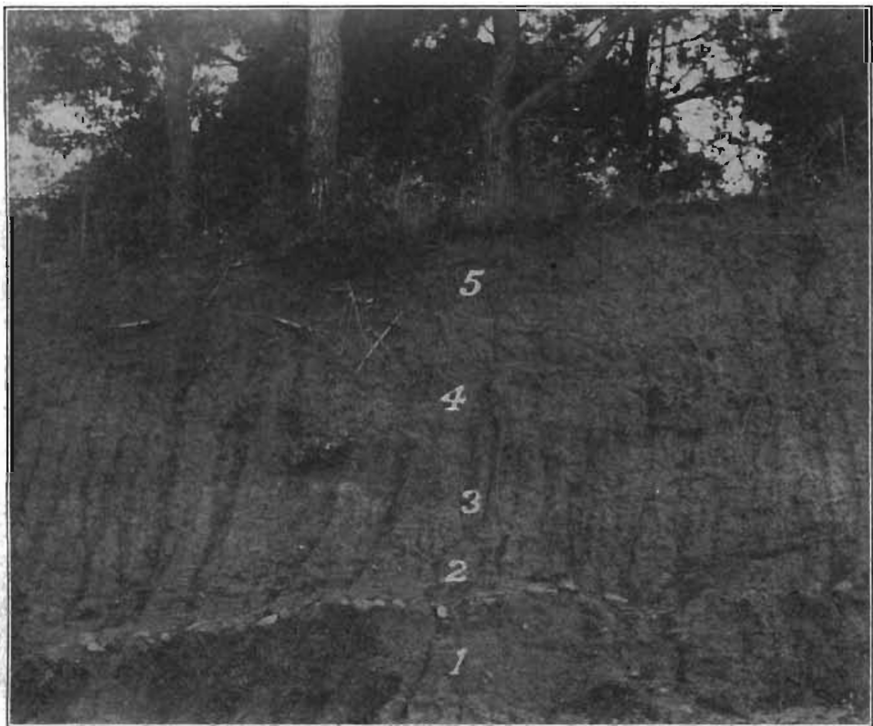


FIG. 46. View of the north side of the road-cut about half way up the east slope of the Little Sioux valley east of Cherokee. Zone number 1 is Kansan till; number 2 is gravel and sand; number 3 is unleached loess with concretions; number 4 is leached loess; number 5 is brown sandy leached clay. The zones of this exposure are shown diagrammatically in the left part of figure 45. (Photo by Kay.)

thickness of all the material above the till is only three or four feet. In this part there are a few pebbles distributed through this loesslike clay zone and at one place on the slope a layer of pebbles exists in its lower part. If this material which is exposed at the crest of the slope were all that was present on the hill it would not be interpreted as loess, and yet it passes laterally into the more definite loess zone.

East of the crest of the valley slope the leached loess is exposed in the shallow cuts of the upland. If the loess zone is three and one-half to four feet thick it may show a thin zone of unleached loess at the base. Unleached Kansan till with small calcareous concretions underlies the loess. On the south side of the road just east of the first ravine east of the schoolhouse on the south line of section 25, is an exposure a sketch of which is shown in figure 47. The east slope of the low hill has a

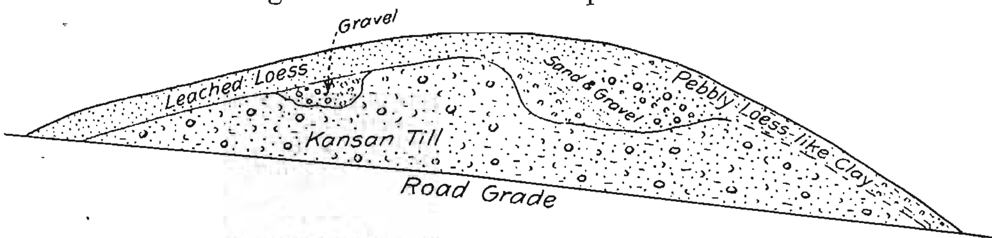


FIG. 47. Sketch of an exposure showing the relation of loess and loesslike clay to the underlying till and gravel mass. Exposure on south side of road in cut just east of the first ravine east of the schoolhouse on the south line of section 25, Cherokee township, Cherokee county.

mantle of about three feet of leached loess resting directly on the unleached Kansan till, which contains calcareous concretions. In the central part of the exposure are several gravel masses inclosed in the till and overlain by the loess. These are included gravel masses in the Kansan till which were exposed at the surface at the time the mantle of loess was formed. The west slope of the hill is steeper because it is on the slope of a small valley, and on this slope the loess mantle is thinner and contains a few pebbles. This material on the west slope has been reworked by slumping down the slope.

East of this locality, along the south line of section 25 and 30, there are a number of cuts which expose four to six feet of loess, and in at least two cases about a foot of unleached loess containing concretions is present beneath the leached material. The first cut east of the southwest corner of section 30 shows at the center Kansan till overlain by two to three feet of dark loess-like clay which contains some pebbles. In either direction this material is thicker and grades into typical loess without pebbles.

DATA CONCERNING THE NATURE AND THICKNESS OF THE LOESS.

A great number of exposures showing the loess were studied and a few of the better sections, most of which are artificial exposures, will be recorded.

From Wall Lake west across Southern Sac and Ida Counties.—At the town of Wall Lake in southern Sac county, a basement excavation just north of the water tank showed the following:

		FEET.
2.	Leached loess, including the soil	5
1.	Unleached loess with a few concretions and some fine sand in thin seams at the base	3

Wall Lake is less than two miles from the Wisconsin boundary, yet this material is unquestionably loess.

At the town of Odebolt, in southwestern Sac county, a basement excavation in the southwest part of town exposed the following:

		FEET.
3.	Leached loess, including the soil	5
2.	Unleached loess	1½
1.	Yellow-brown Kansan till, exposed	1

Another excavation one square farther south showed:

		FEET.
2.	Leached loess, with the soil	4
1.	Yellow-brown Kansan till	2

A trench on the main street in the east part of town exposed:

		FEET.
2.	Leached loess	3
1.	Yellow sand with pebbles, exposed	6

The trench exposure was open for 150 feet and showed no changes laterally.

At Arthur, in eastern Ida county, a basement excavation in the north part of town showed four and one-half feet of leached loess to the base of the opening. This place is within the region of unquestioned Kansan drift and loess, yet this leached loess is identical with that found farther east at Odebolt and Wall Lake. The loess thickens to the west across southern Ida and Woodbury counties and is commonly exposed in the road-cuts. In many of the exposures the unleached concretion-bearing loess comes to the surface.

Five and a half miles south of Odebolt near the quarter corner on the west of section 26, Wheeler township, a gravel pit in Porter creek valley showed the following:

		FEET.
3.	Leached loess	5
2.	Sand with seams of loesslike clay	3½
1.	Fresh, clean gravel	14

In another part of the exposure the loess is seven feet thick and is leached to a depth of only two feet. This is typical calcareous loess containing concretions and a few small snail shells. This valley extends southward to Boyer river at Boyer in Crawford county, and in its lower course, gravel material overlain by fossil-bearing calcareous loess is exposed in several railway and other cuts.

From Early west across Northern Sac and Ida Counties.—At Early in west-central Sac county an excavation at the schoolhouse in the northwest part of town showed the following:

		FEET.
2.	Leached loess	3
1.	Unleached yellow Kansan till, exposed	4

Early is less than two miles from the Wisconsin boundary, and exposures along the road leading north from Early show that the leached loess, about three feet thick, continues to the edge of the Wisconsin drift.

About five miles northwest of Early a railway cut at the southwest corner of section 28, Eden township, showed the following:

		FEET.
3.	Leached loess	3½
2.	Unleached loess	½
1.	Typical Kansan till with concretions, exposed	6

At Schaller in northwestern Sac county the following section was measured:

		FEET.
4.	Leached loess, including the soil	3½
3.	Unleached loess	½
2.	Sand	½
1.	Unleached yellow-brown Kansan till, exposed	2

At Galva in northeastern Ida county a trench in the road in the south part of town showed the following:

		FEET.
4.	Leached loess	6
3.	Unleached loess	1
2.	Sand with cobbles	2
1.	Unleached yellow-brown Kansan till, exposed	1

Another exposure in the east part of town showed leached loess to the bottom of a trench four feet deep.

West of the Maple valley at Galva is the unquestioned loess region and the unleached loess is exposed in many road-cuts, as in the northwest quarter of section 27, Galva township, where it has a thickness of at least ten feet.

At Holstein in northcentral Ida county a trench exposure on the street showed the following:

		FEET.
4.	Leached loess, including the black soil at top	4½
3.	Unleached yellow-brown, mottled loess with a few concretions	4½
2.	Seam of sand	¼
1.	Unleached yellow Kansan till, exposed	2

The divide cut on the railway one mile east of Holstein exposed the following:

		FEET.
3.	Leached loess	4
2.	Unleached loess	2
1.	Yellow Kansan till with concretions, exposed	3

This series of exposures from Early through Schaller and Galva to Holstein extends from the Wisconsin boundary well within the unquestioned loess-covered Kansan. The loess is thicker to the west, as is shown by the increase from three feet at Early to nine feet at Holstein, and with this increased thickness the unleached zone appears, but the leached loess is the same at all places. Within a short distance west of Holstein the country is rugged and loess exposures are common in the road-cuts. A series of good exposures of loess existed in 1916 along the road paralleling the railway on the south from Cushing to Correctionville. The loess is thicker to the west across Woodbury county to Sioux City, where loess exposures thirty to fifty feet deep may be seen.

From Storm Lake west across Buena Vista, Cherokee and Plymouth Counties.—At Storm Lake a basement excavation on the main street showed the following:

		FEET.
4.	Soil	2
3.	Leached loess	2
2.	Unleached loess	1
1.	Unleached Kansan till, exposed	2

This exposure is within one mile of the Wisconsin boundary and in other exposures in the east part of town the loess may be found to and possibly beneath the Wisconsin drift.

At Alta excavations along the railway just west of the station and in the divide cut in the west part of town showed three feet of leached loess with soil, overlying unleached yellow Kansan till with some concretions. This is at the crest of the great divide.

In southwestern Buena Vista county, in the southwest quarter of section 21, Maple River township, on the farm of Will Litzenburger, a well boring passed through five feet of loess, and at the time of the writer's visit the well had been sunk to a depth of fifty feet, all in yellow Kansan till. This is an exceptional thickness for the oxidized zone of the Kansan till.

At Cherokee, at the new hospital in the north part of town, about fifty yards northwest of the building, a trench showed the following:

		FEET.
4.	Soil	2
3.	Leached loess	2½
2.	Unleached loess with a few concretions and containing thin layers of fine sand at base	1
1.	Sand with pebbles	2

This exposure is on the high gravel bench of the Little Sioux valley about 125 feet above the river. The position of the loess over the sand and gravel of the bench area shows that the gravel deposit of the high benches is older than the loess. A cut on Spruce street in the north part of town just east of Second street shows three feet of loesslike material overlying the gravel. The upper two feet of the zone is leached.

In 1916 a road in the northeast part of section 28, Cherokee township, had been recently graded and showed a number of good sections. The first cut north of the Cherokee water tank showed the following:

		FEET.
4.	Leached loess, including the soil	4
3.	Unleached loess	2
2.	Sand and pebble layer	⅓
1.	Yellow-brown Kansan till with concretions, exposed	2

The third cut north of the tower, located at a bend of the road (telephone pole 1554), showed the following:

		FEET.
5.	Leached loess, including soil	4½
4.	Unleached loess	1½
3.	Sandy loess	1½
2.	Pebble and sand layer	½
1.	Yellow-brown Kansan till with included gravel masses	2

In the loess zone of this exposure a section of a small elephant tusk about six inches long was found. Other cuts northwest to the viaduct across the spur of the railway show similar exposures. The first road-cut east of this viaduct showed:

		FEET.
3.	Leached loess	6
2.	Unleached loess	2
1.	Fine-grained clayey, sandy material	2

A railway spur in the southeast quarter of section 21 and the north part of section 28, on the grounds of the Cherokee State Asylum, showed in 1916 some newly made cuts. At the edge of the creek valley in the southeast quarter of section 21 the cuts show thirty feet of typical brownish yellow Kansan till with large included sand and gravel masses. A thin zone of leached loess exists at the top of the cut.

The largest cut along this spur is at and just south of the north line of section 28. The Kansan till rises fifteen to twenty feet in the cut and has included in it as lenses much material that is not typical Kansan. One section which was exposed by cleaning the face of the cut measured as follows:

		FEET.
9.	Leached loess, including the soil	6
8.	Unleached loess	2
7.	Alternating layers of loess and fine sand	4
6.	Pebble layer	1/6
5.	Unleached yellow Kansan till with concretions	3
4.	Unleached blue-gray pebbly till with a few concretions	2
3.	Noncalcareous dark brown pebbleless clay	3½
2.	Blue-gray till similar to No. 4	2½
1.	Yellow Kansan till, exposed	2½

All the material below the pebble layer (No. 6) is considered Kansan drift, numbers 4, 3 and 2, which are not typical Kansan, being interpreted as included material. It appears that the noncalcareous brown clay (No. 3) is material gathered up from some surface by the Kansan ice-sheet. The marginal parts of this mass became mixed with the Kansan till and form horizons 4 and 2 above and below it. The oxidized zone of the typical Kansan extends below the base of the cut (No. 1). Just south of the section line in this cut there are several masses of Nebraskan till included in the Kansan. One of these, an elongate lens, is more than fifty yards long and six to eight feet thick and is somewhat mixed with yellow Kansan till. Another smaller mass also consists of noncalcareous Nebraskan till.

The upper contact of the Kansan till in this cut shows a buried relief **not** expressed in the present topography; that is the small irregularities in the Kansan surface were filled in and obliterated by the loess.

Near the south end of this large cut, where the Kansan till has passed below the grade, the following section was measured:

		FEET.
3.	Leached loess, including the soil	6
2.	Unleached loess	3
1.	Alternating layers of loess and fine sand	4

A small cut at the level of the upland just northwest of the Institute buildings showed:

		FEET.
3.	Leached loess with soil	4½
2..	Unleached loess	1
1.	Kansan till	2

This illustrates the usual thinning of the loess on the hill tops as compared with the east or north slopes.

About a mile southwest of Cherokee, in the north part of the southeast quarter of section 33, on the north slope of a ravine valley, are some abandoned clay pits which show the following section:

		FEET.
4.	Leached loess, including the soil	5
3.	Unleached loess containing a few concretions	15
2.	Sandy, silty loess with a few layers of fine sand	5
1.	Slumped to bottom of pit	10

The material in the lower part of the exposure (No. 2) has a faint horizontal banding and may be partly waterlaid. It grades upward into the more typical loess, which here has an exceptional thickness for this region. The unleached loess (No. 3) is filled with the brown threadlike rootlet impressions which are characteristic of the loess. The top zone of leached loess is the same as that which is found in most road-cuts. This mass is below the general level of the country and its great thickness may be due to accumulation in the lee of the upland to the west. The deposit was formerly used for the manufacture of brick and tile.

Western Cherokee and eastern Plymouth counties have a loess mantle of sufficient thickness to conceal the till on all but the steeper slopes. The shallow road-cuts show dark soil passing into the leached loesslike clay below. Some cuts of four feet or more in the loess show the unleached phase. An exposure just south of the northwest corner of section 29, Sheridan township, Cherokee county, showed the usual horizons:

		FEET.
4.	Leached loess	3½
3.	Unleached loess	2
2.	Fine yellow sand	1½
1.	Yellow Kansan till, exposed	1

On the west side of the West Fork of Little Sioux river in the south part of section 23, Amherst township, a gravel pit showed the following section, which includes the horizons commonly existing along the valleys:

		FEET.
5.	Leached loess	3
4.	Unleached loess with pebbles in basal 6 inches	1
3.	Sand with a few pebbles and becoming more clayey above	4
2.	Medium-grained gravel with a few cobbles	5
1.	Fresh yellow Kansan till, exposed	2

Similar conditions continue for several miles west of LeMars, but within the more rugged country the loess is thicker and the unleached concretion-bearing phase is at the surface.

O'Brien and Sioux Counties—At Sutherland in southeastern O'Brien county, at the southwest corner of town, a post auger hole was bored through soil and leached loess to a depth of three feet and eight inches without reaching the base of the loess. In the east part of town are several pits in the gravel deposit along the headwaters of Murry creek that show three and a half feet of leached loess overlying the gravel.

Road-cuts in northern Cherokee and O'Brien counties show the black soil, which at a depth of twelve to eighteen inches grades into the yellow leached loess. If the exposure is over three feet deep the unleached Kansan till is commonly shown. A good series of road-cuts was exposed in 1916 along the township line road leading south from Primghar. One of these road-cuts in the southwest quarter of section 7, Highland township, showed three and a half feet of loess overlying till.

About half a mile north of the Sheldon railway station in a cut on the Chicago, Minneapolis, St. Paul and Omaha railway, the following section was measured:

		FEET.
4.	Soil	2
3.	Leached loess	1½
2.	Unleached loess	2½
1.	Till with calcareous concretions, exposed	1

Farther north near the crossing of Floyd river, abandoned gravel pits show a zone of leached loess three to five feet thick overlying the gravel. The base of the loess here contains a few pebbles (page 393).

In Sioux county, Sheridan township, at the southwest corner of section 29, an excavation for a storm cave in the schoolhouse yard showed eight feet of loess, the larger part of which is leached. Below the loess is a thin layer of sand and pebbles and then the unleached Kansan till. Two miles north at the southeast corner of section 18, in the schoolhouse yard, material thrown from an excavation for a storm cave showed that the loess has a similar depth, for the till was not reached. At the northeast corner of section 32, Lincoln township, an excavation for a cistern showed ten feet of loess without reaching its base. Careful search on the walls of the cistern and of the material thrown out did not show a single pebble.

Farther west in Sioux county, loess exposures are numerous but commonly show only the leached loess, except in the more rugged region near Big Sioux river where unleached concretion-bearing loess is found.

Clay and Dickinson Counties.—In Clay county, Douglas township, near the quarter corner on the south of section 25. an open trench showed the following:

		FEET.
4.	Soil	1
3.	Leached loess	1
2.	Unleached loess with a few concretions	½
1.	Typical Kansan till with a few concretions, exposed	2

This exposure is just half a mile west of the north-south center line of Clay county, and within four miles of the Wisconsin boundary across the Little Sioux valley, but the loess zone, although thin, is sufficiently well developed to be definitely recognized. To the north in central Clay county, towards Spencer, the loess horizon is thinner and in some places where it is less than two feet thick, it is not a definite loess zone. It forms, however, a thin mantle of dark to yellow clay commonly concealing the till and when it is traced from the counties to the west it is seen to be very definitely the equivalent of the loess. This is the condition over northern Clay and southwestern Dickinson counties outside the Wisconsin boundary.

Osceola and Lyon Counties.—In southeastern Osceola county, Harrison township, on the south line of the southwest quarter of section 2, a post auger hole gave the following section:

		FEET.
3.	Soil	1½
2.	Leached loess	2
1.	Kansan till	

On the west line of section 3. Harrison township, an open trench showed the following:

		FEET.
3.	Soil	1
2.	Unleached loess with concretions and iron tubules	1½
1.	Kansan till, exposed	3

On the north line of the northwest quarter of section 28. Ocheyedan township, a post auger hole gave the following section:

		FEET.
3.	Soil	1½
2.	Unleached loess with concretions	1½
1.	Pebble zone	

All three of these sections are within one mile of the Wisconsin drift-boundary.

Road-cut exposures in southern Osceola county commonly show the leached loess, which has a thickness of two and one-half feet and rests directly on the unleached Kansan till.

At Sibley, a trench just east of the intersection of the main streets showed the following section:

		FEET.
4.	Fill, chiefly of black soil	2
3.	Dark, peaty soil, passing into leached loess	2½
2.	Unleached loess with concretions and dark rootlike threads through it	1
1.	Typical brownish yellow Kansan till, exposed	1

This trench was open from the intersection of the main streets south for two blocks to the Rock Island railway and the loess was essentially the same all the way. At the first street crossing (near Windsor Hotel) gravel appears below the loess and is thicker to the south until the till drops below the bottom of the trench. The gravel was said to be five feet thick near the railway. An open trench east of the park in the northeast part of town showed similar relations of the loess, till and gravel (page 386, figure 44), and the gravel of the pits in the east part of Sibley is overlain by three to four feet of leached loess.

At Little Rock in northeastern Lyon county, a cellar excavation in the west part of town showed the following:

		FEET.
4.	Soil, passing to yellow clay at base	1½
3.	Leached loess	1
2.	Pebble band	¼
1.	Unleached yellow Kansan till, with small calcareous concretions near the top, exposed	6

Other exposures in the region show two and a half to three feet of leached loess, as near the southeast corner of section 35, at the northeast corner of section 22, and near the southeast corner of section 18, all in Elgin township. Farther west, in Lyon county, the leached loess may be seen in many exposures, and near the Big Sioux the unleached loess with concretions is commonly exposed.

Southern Nobles County, Minnesota.—The study of the loesslike clay was continued about ten miles north of the state line to Adrian in Nobles county, Minnesota. At the southwest corner of section 28, Ransom township, less than two miles from the Wisconsin drift-boundary, a post auger hole exposed two and one-half feet of soil and loesslike clay overlying yellow Kansan till with calcareous concretions.

At the quarter-corner on the east line of section 19, Little Rock township, a post hole showed the following section:

	FEET.
4. Soil, passing to leached loess below	1½
3. Loesslike clay; slightly sandy and with a few concretions in lower six inches	1
2. Sandy pebbly zone	½
1. Yellow-brown unleached Kansan till, with small calcareous concretions	

At the quarter-corner on the east of section 12. Grand Prairie township. a post hole showed the following:

	FEET.
3. Soil and leached loess	2½
2. Pebbly band	½
1. Yellow till	

Three miles south of Adrian at the southeast corner of West Side township a post hole showed the following:

	FEET.
3. Soil, becoming yellow at base	2
2. Unleached loess, slightly sandy	2
1. Yellow-brown Kansan till	½

The last three records are located along the crest of the ridge running south from Adrian which Professor Wilder interpreted as the Altamont moraine.[46]

Three miles west of Adrian at the southeast corner of section 16, West Side township, the road-cut showed two to three feet of soil and loesslike clay (leached loess). A few inches at the base of this zone is unleached in part of the exposure. Below this horizon is a coarse oxidized gravel which contains some masses of fresh Kansan till some of which are as large as two feet in diameter. The gravel zone is exposed to a depth of three to four feet and the basal part is cemented to a conglomerate.

The loess mantle in the Adrian region is thin, as the area is far to the northeast of the region of heavy loess, and so is similar to Clay and southern Dickinson counties farther south. The exposures east of Adrian are not of the typical leached loess, but sand grains exist more or less throughout the whole of it. It is, however, the equivalent of the loess mantle.

ORIGIN AND AGE OF THE LOESS.

That loess is of eolian origin has become firmly established.[46a] The chief source of the loess material of our region was the valley flats of the rivers forming the west line of the state, especially Missouri river, and because the prevailing winds of

[46]Iowa Geol. Surv., Vol. X, pp. 132-135, 1900.

[46a]A bibliography on loess is given in Iowa Geol. Survey, Vol. XXII, pp. 582-592. Professor Shimek discusses the matter briefly, from the standpoint of the evidence of western Iowa, in Vol. XX, pp. 399-405, and lists in a footnote on page 399 some of his more important papers on the subject.

the region are from the west, the thickness deposited and the extent of the mantle are greater to the east than to the west of the valleys. The greatest thickness was deposited near the Missouri and Big Sioux river valleys in western Woodbury and Plymouth counties, where the distinctive loess-formed topography now exists. With increasing distance to the east and northeast the thickness of the loess deposited was less and was only two to three feet over the eastern part of the Kansan drift-region of our area.

Little evidence exists in northwestern Iowa as to the exact age of the loess. It followed the accumulation of gravels in valleys of a region having a mature topography which was developed from the gumbotil plain of post-Kansan age. It preceded the Wisconsin epoch. The loess of eastern Iowa is closely associated with the Iowan drift-sheet and is commonly considered to be of Iowan age. The loess of western Iowa is believed to be of the same age.

The significance of the determination that there is loess over the entire extra-Wisconsin region is that it makes the drift of the entire region pre-loess in age, and since it was not possible to differentiate two drifts in the region, the whole extra-morainic portion of northwestern Iowa is classed as loess-covered Kansan.

CHAPTER IV

THE ASSOCIATED GRAVELS.

The Kansan till of northwestern Iowa has much gravel associated with it. Some of the gravel is in masses inclosed within the till, some is in masses at or near the surface, some in layers interbedded with the till and some is in bedded deposits in the valleys. The gravel in these several positions is very similar and seems to have had a common origin.

Gravel and Sand Masses Included in the Till.

GENERAL CHARACTERISTICS.

There is in the till of northwestern Iowa a large quantity of gravel and sand in the form of inclosed masses (gravel bowlders). These masses were observed in cuts, and in the fresher and steeper valley side exposures. When they are penetrated by bored or drilled wells, they are usually reported as gravel layers; but in dug wells their true nature is revealed in most cases. Most wells which stop in gravel masses which are supposed to be gravel layers give out in a short time.

The gravel masses differ in size from small pockets a few inches across to huge masses ten to twenty feet or more in diameter. Common dimensions are three to six feet. A mass exposed in a railway cut in section 6 of Douglas township, Ida county, about one and a half miles south of Washta, is thirty to forty feet by fifteen to twenty feet, and another in a Chicago and North Western railway cut just east of Sioux Rapids is twenty to twenty-five feet across.[47]

Most of the sand and gravel masses are roughly equidimensional or compressed in a vertical direction, but some are irregular in shape. Most of them have a rounded form, but several were seen with corners projecting into the till in such ways as could have been assumed only when the gravel masses were frozen.

The sand and gravel of the bowlders is as a rule stratified. The beds vary in position from approximately horizontal to vertical, and locally the layers are contorted. The bedding of a particular bowlder is as a rule a unit, but a few cases were observed which show faulting and some crushing, and in many cases the bedding is obliterated at the margin of the mass.

The material of these bowlders is sand, fine gravel, and some silts. Most of it is slightly ferruginous so that an iron-stained dust is released when the gravel is displaced. There are a few masses composed of old, badly rusted gravel. In general the coarse gravel is rusted and partly decomposed, while the finer material is fresh and unaltered. The coarse-grained igneous pebbles are more decomposed than the finer-grained ones, and the darker colored varieties (containing mica and hornblende)

[47]Professor Calvin described (Proc. Davenport Acad. Sci., Vol. 10, pp. 27-28, and figs. 9-13) a number of these masses inclosed in Kansan till, exposed in the railway cuts at Afton Junction and Thayer in Union county, and interpreted them as masses of Aftonian gravel which had been plowed up by the Kansan ice-sheet and inclosed in the till. One of these (p. 28 and fig. 12) is over a hundred feet long and rises more than twenty feet above the base of the cut.

more than the lighter colored. Most limestone pebbles are altered slightly at the surface and a few are altered to the center or decomposed to clay iron-stones.

Seventeen analyses of gravel associated with till were made, but there is some question concerning the correct interpretation of a number of these as gravel bowlders. The analyses of the nine positive cases average 39 per cent of igneous rocks and 61 per cent sedimentary rocks, 52 per cent being gray limestone. The average for the seventeen analyses is 41 per cent of igneous rocks and 59 per cent of sedimentary. Small rounded balls of till (clay-balls) were seen in a few of the gravel bowlders.

In most cases the till is fresh up to the edge of the gravel bowlder, but in a few cases a thin shell, concentric with the border, is stained, altered, and partly cemented with ferruginous material. Also in a few cases the gravel is cemented in a shell around the outside of the mass. This alteration and cementation is a contact phenomenon which has been produced since the inclusion of the gravel mass.

DESCRIPTION OF SOME TYPICAL GRAVEL MASSES.

Little Sioux river valley across northern Buena Vista and southern Clay counties has been cut deeply into the till and both natural and artificial exposures along the valley show many gravel bowlders. A large sand bowlder in a cut of the Chicago and North Western railway just east of Sioux Rapids has been noted above (page 358), and gravel masses are numerous in several cuts a little farther east. In the southeast quarter of section 3, Barnes township, Buena Vista county, just east of where the railway crosses the terrace area is a cut, which, although old and slumped, showed a great number of sand bowlders.

Near the top of the bluff north of the schoolhouse at Peterson, there is a pit excavation thirty to forty feet across and fifteen to twenty feet deep. The material excavated was supplied by several large sand and gravel bowlders packed closely together. Some of the vertical contacts with the inclosing till were exposed. Some of the material is coarse gravel, some is fine sand, and some is silt. The material is stratified, and the beds now stand at various angles. Near the top of the slope leading to the upland southwest of Peterson the road-cut exposed a lens of sand fifty feet long and ten feet thick. The material is slightly iron-stained and around the edges of the mass is somewhat contorted.

A large sand bowlder is exposed in a road-cut on the slope toward the river in the north half of section 26, Waterman township, O'Brien county, and at about the center of section 14 of the same township, the east bluff of Waterman creek shows several gravel bowlders, four to ten feet across, inclosed in Kansan till.

In the north bluff of Storm lake, near the center of section 4, Hayes township, Buena Vista county, there are several irregular masses of loesslike silt and sand. At several places the layers making up the masses are contorted and crumpled and even broken off, so that they abut against other parts of the mass in which the layers have a different angle.

Just east of the center of section 22, Brooke township, Buena Vista county, the west bank of a ravine exposes an old-looking, ferruginous sand and gravel with some fine silty layers. The exposure has a length of about fifty feet and rises forty feet above the ravine bed to the top of the slope. In either direction the ravine slope is grassed over and the basal part of the exposure is too badly slumped to show material in place, but Kansan till was exposed in the ravine bed just south of the exposure and rose six to eight feet above the ravine bed just north of the exposure. There is little doubt that this is a great gravel mass included in the Kansan till. The bedding of the mass dips slightly to the south and apparently back into the bank to the west. Ferruginous concretionary cementation has affected part of the sand and has formed irregular shaped masses some of which are more than a foot across. The material composing this mass is much more decomposed and altered than is common for the gravel masses.

In the north part of Cherokee, in an alley just east of Second street and south of Spruce street, there is a large mass of silt and sand, partly inclosed in till. The material is somewhat contorted and the layers are in part steeply inclined. A series of road-cuts in Kansan till in the northeast quarter of section 28, Cherokee township, showed in 1916 a large number of inclosed gravel masses. The face of one of these cuts near the north line of the section showed almost as much gravel as till.

Other gravel masses were seen in the south bluff of Mill creek, between the bridges in the northeast quarter of section 23, Cherokee township; in the bluffs of the creek valley of section 24, Cedar township; along the creek valley through sections 11 and 10, Pilot township, south of Cherokee; and at many other places throughout the area. In fact most large exposures of till show some of these gravel masses.

In the south bank of a ravine in the south part of section 10, Stockholm township, Crawford county, about a quarter of a mile west of the railway there are several gravel bowlders four to ten feet in diameter and some smaller ones of sandy silt or silt. The material of these gravel bowlders is somewhat iron-stained and in one case the gravel around the border is partly cemented, while in another the surrounding clay is iron-stained for two to three inches, concentric with the border of the bowlder. The analysis of pebbles from one or these bowlders gave 30 per cent igneous rocks and 70 per cent sedimentary rocks, 7 per cent of which were clay-balls. The layers of the gravel composing the bowlders are inclined.

In the south bank of the road-cut just east of the railway crossing in the east part of section 15, east of Sioux Falls, South Dakota, there is a mass of gravel completely inclosed in the Kansan. The gravel is rather fresh and contains shale pebbles and drift pebbles. The analyses showed 49 per cent igneous rocks and 51 per cent sedimentary. The bedding of the mass is inclined.

THE ORIGIN OF THE SAND AND GRAVEL BOWLDERS.

The presence of the rounded, rectangular or angular masses of stratified gravel, sand and silt completely inclosed in the till has been noted. It has also been noted that some of these gravel masses have angular corners projecting into the till, and that the layers of the masses have various positions. These points indicate that the gravel masses are fragments of larger deposits which were broken up, probably while they were in a frozen condition, and the fragments were incorporated like rock bowlders in the till. However, what was the origin of the gravel deposit that was thus broken up and what was its age? Two hypotheses are considered. (1) It was an interglacial deposit which existed in the region prior to the Kansan ice-epoch; (2) It was an outwash deposit laid down in front of the advancing Kansan ice-sheet which a little later plowed it up.

An interglacial deposit should consist largely of pebbles of the harder, more resistant types of rock that are left after the weaker ones have been worn out or decomposed, and in this respect the gravel of these masses does not seem to be interglacial. The gravel masses exposed in the railway cuts at Thayer and Afton Junction were interpreted as masses of Aftonian gravels, which are very abundant in that region. However, in northwestern Iowa, as will be shown later, the Aftonian gravels are practically absent.

In general appearance and freshness the pebbles of the gravel masses bear a close resemblance to pebbles picked directly from the Kansan till. The clay-ball pebbles also have a definite bearing on the age of the deposit. Since these clay-balls are of Kansan till, the gravel deposit in which they exist cannot be older than Kansan, and is therefore not Aftonian. Since the gravel masses are inclosed in the Kansan till these masses cannot be younger than the Kansan.

The gravel masses are therefore considered contemporaneous with the Kansan till-sheet which incloses them and the gravel is interpreted as having been deposited beyond the front of the advancing ice-sheet which a little later plowed it up and incorporated fragments of the frozen mass in its drift.

The Gravel Hills.

At a number of places within the area of the Kansan drift there are mounds composed of gravel and sand. Their slopes are gentle and few of them are more than fifteen to twenty feet above their surroundings. In form, they resemble the kames of the Wisconsin drift, though they are much less conspicuous. Some of them are isolated, and some are in groups.

NATURE OF THE GRAVEL.

The gravel of these hills is as a rule fresh, or but slightly altered. Some of the exposures, however, show iron-stained and decomposed gravel, and a few show an abundance of chalky, calcareous material either as weathered limestone pebbles or as matrix between the pebbles. Extreme alteration was seen near the surface at a few places, giving an iron-stained clayey mass of pebbles.

As in all types of gravels of our region, gray limestone pebbles predominate to such an extent as to make a light colored gravel. In twenty-three analyses made in gravels of this type the limestone pebbles average 56 per cent of the whole. Shale pebbles are present and in certain layers are even abundant. Grains of shale also are abundant in the sand. A characteristic and distinctive feature of these gravel hills is the presence of small rounded masses of glacial clay (clay-balls) among the pebbles. These differ in size from a fraction of an inch to six inches in diameter. They are recorded in seventeen of the twenty-three analyses of gravel from these hills and some of the analyses not recording them were made before the clay-balls were noted. The average for the twenty-three analyses is 11 per cent. The percentage is twenty-six or below in all analyses but one, where it is 59. The igneous rock content ranges from 17 per cent to 35 per cent, except in one analysis where it drops to 8 per cent because of the large number of clay-balls. Counting the clay-balls as sedimentary, the average total of sedimentary rocks is 75 per cent, and the average total of igneous rocks is 25 per cent.

The percentage of granite and other igneous pebbles generally is low in comparison with that shown in analyses from gravel deposits of other types. This is due to the large number of clay-balls in these gravels, which by their presence lower the percentage of all other kinds of pebbles. The decrease, however, comes mainly in the igneous pebbles, for the comparison is with gravels that have been more waterworn, and which therefore contain a smaller percentage of pebbles of the softer materials. Chief among these softer pebbles are the clay-balls which would be destroyed by wear, and thus would increase the percentage of all other kinds. But some pebbles of other soft materials would be destroyed by the transportation, so that the increase would be most apparent in the harder types. The increase in the percentage of limestone pebbles due to the destruction of clay-balls apparently was offset by the destruction of some of the softer limestone pebbles, with no apparent gain in limestone.

If these gravel hills are kames or some other type of deposit directly associated with the ice, softer material would naturally be more abundant than in gravels that were subjected to longer transportation and wear. On the other hand, waters flowing well up in an ice-sheet, as may be the case with waters forming kames, probably would yield a larger percentage of igneous pebbles than waters draining from the base of the ice.

There is in some cases a great range in the composition of the gravel in the same hill. This is particularly prominent in the case of shale pebbles, for certain layers contain a percentage far above normal, and some layers are made up almost entirely of small grains of shale. In other constituents also there is in some cases a considerable range. No differences were detected that differentiate the deposits of different localities. Analyses from gravel hills a hundred miles apart are as likely to be similar as those from hills near together.

DISTRIBUTION AND DESCRIPTION OF THE GRAVEL HILLS.

Northeastern Lyon County.—A number of gravel hills in the northeast corner of Lyon county, north, northwest and west of Little Rock, form the most conspicuous instances of these hills in the Kansan area. Most of them are below the general upland level and are on the slopes of Little Rock river valley. Most of them rise only ten to fifteen feet above their surroundings, but one in the southeast quarter of section 23 rises twenty-five feet above its surroundings, enough to make it a rather prominent feature, especially from the valley to the south. It is figured in the Lyon county report[48] and there interpreted as part

[48]Iowa Geol. Surv., Vol. X, p. 133, 1900.

of the Altamont moraine. A group of hills just north of Little Rock, near the center of section 26, contains several gravel pits in relatively fresh material, while the highest hill in the southeast quarter of section 23 shows beneath the surface several feet of ferruginous, decomposed coarse gravel.

In the southwest quarter of section 27 there are a number of gravel hills. A pit in the one at the southwest corner of the section shows a coarse somewhat rusted gravel in which the coarse-grained igneous pebbles crumble readily. The gravel of this exposure, as well as that of section 26, contains many clay-balls. Other low gravelly hills, without exposures, are found in the west half of section 34 and the east half of section 33.

Southwestern Nobles County, Minnesota.—A large number of gravel hills are found in the southwest part of Adrian, Minnesota, and in the northeast quarter of section 23, half a mile farther southwest. A road-cut in one of these hills on the north line of the northeast quarter of section 23 showed a great mixture, including coarse dirty gravel with clay-balls; ferruginous bowldery deposits in which many of the dark igneous bowlders are rotten; fine fresh sand; great masses of till; and mixtures of gravel, bowlders and till. The areas northwest of Little Rock and southwest of Adrian were interpreted by Professor Wilder as parts of the Altamont moraine of Wisconsin age.[48a]

Three miles south of Adrian, in the southwest quarter of section 36, West Side township, a pit in a low hill on the north slope of a shallow valley shows in part coarse pebble beds, and in part fine gravel and sand. Clay-balls are abundant in the coarser part, an analysis giving 16 per cent. The coarse-grained dark igneous pebbles crumble easily and most of the limestones are coated brown. In a part of this hill the layers are steeply inclined and in these layers the laminæ lie at an angle of 80 degrees.

Western Osceola County.—In the west part of Osceola county there are low gravel hills on the north slope of a broad, shallow valley in the west part of section 5, West Holman township, and six miles south in the southwest quarter of section 5, and the southeast quarter of section 6 of Gilman township. In the hill in southwest 5, Gilman township, a pit exposure showed about three feet of coarse ferruginous gravel resting upon fresher finer-grained material. Clay-balls are very abundant, amounting to 25 per cent of the total contents in one analysis, and on the pit face one was exposed for each square inch of surface.

Northern O'Brien County.—Gravel hills are found along the headwaters of Floyd river in northern Franklin township of O'Brien county. On both slopes of a tributary valley in the southwest quarter of section 4, there are several hills with gravel exposures and hills which have the same topographic form appear on the north of the main valley in the southeast quarter of section 4. The exposures seen were shallow and the gravel was greatly decomposed. A low hill just northwest of Sheldon in the central part of section 25, Grant township, Sioux county, is probably a gravel hill.

In a pit in a low mound three miles northwest of Hartley, near the center of section 24, Lincoln township, the gravel had been worked out in several places and there was exposed a vertical contact between the gravel mass and the till. This gravel mass, partly inclosed within the till, occupies an intermediate position between the gravel hills and the included masses of gravel.

[48a] Iowa Geol. Surv., Vol. X, pp. 132-135, 1900.

Farther east, in Waterford township of northeastern Clay county, there are several low hills or mounds apparently composed of gravelly material.

Along Willow Creek in Southern O'Brien County.—One of the regions of greatest abundance of the gravel hills is along Willow creek west of Calumet in southern O'Brien county, where more than a dozen of these hills are present in the north parts of sections 22, 21 and 20 and the south parts of sections 16 and 17. Liberty township (Plate XV). About half of these have exposures showing sand and gravel. The two best exposures are in gravel pits in the north part of section 22 and will be described somewhat in detail.

Near the quarter-section corner on the north of section 22 there is a low mound near the top of the valley slope with a pit twenty to twenty-five yards across and ten to fifteen feet deep. The material exposed is sand and fine gravel, with some very fine-grained horizons showing extremely fine lamination. Throughout the lower part of the mass the horizons are inclined, with a strike N. 25°-30° W. and a dip of 45°-50° in a direction south of west. The individual horizons are cross-bedded and laminated. Where the tilting of the mass increased the inclination of the cross-bedding laminae, these now stand at an angle of 60°-70°. Where the laminae were originally inclined in the direction opposite to the direction of tilting of the mass, the original inclination was overcome and the laminae are now inclined 20° to 30° in the opposite direction (figure 48).

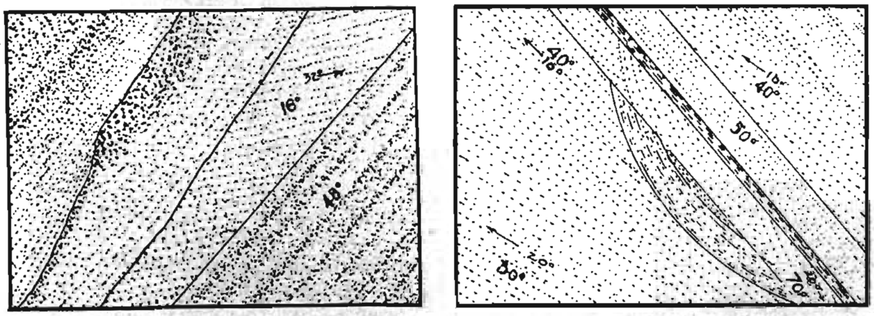


FIG. 48. Sketches showing cross-bedding and basin structure of sand exposed in a pit in a gravel hill in the northwest corner of the northeast quarter of section 22, Liberty township, O'Brien county. The present inclination of the beds is given in the more prominent figures. The direction of inclination before the tilting of the gravel mass is indicated by the arrows, and the angle by the less prominent figures. The position of the beds at the time of deposition may be shown by tilting the figure on the left, to the right about 50 degrees, and the figure on the right, to the left the same amount.

Gray limestone pebbles are by far the most abundant, forming 66 per cent in one analysis. A few shale pebbles appear in all the material, but are most abundant in the finer gravel layers where they form a third to a half of the whole number, and decrease in abundance with the increase in size of the pebbles. Interbedded with these layers containing much shale are other layers of nearly the same coarseness that have only a few shale pebbles.

The following section records the material shown in this pit which dips to the southwest (figure 49).

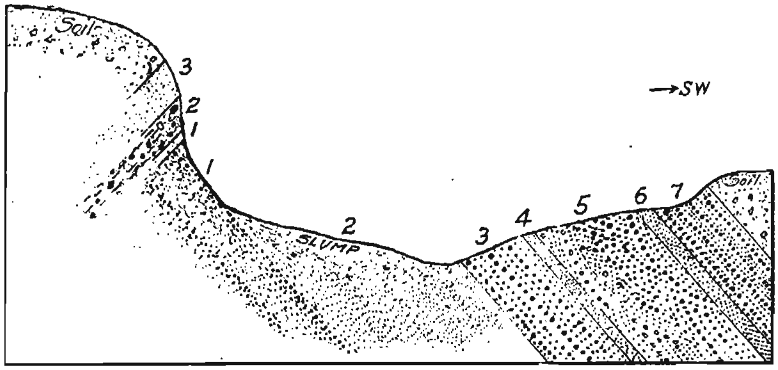


FIG. 49. Cross section of pit in the northwest corner of the northeast quarter of section 22, Liberty township, O'Brien county, showing the structure and the relation of the parts described in the text. The numbers on the figure are the numbers of the zones of the sections recorded below.

		FEET.
7.	Fine reddish gravel, exposed	4
6.	Very fine-grained yellowish gray sand, cross-bedded and finely laminated	1
5.	Coarse sand and fine gravel, laminated and cross-bedded in part; coarse gravel and pebbles at base	7½
4.	Fine cross-bedded sand	1
3.	Sand and fine gravel; some layers contain much shale	4½
2.	Slumped slope of fine sand	11
1.	Coarse sand, giving place to fine clayey sand, exposed	2

Resting across the edges of the lower horizons of the section just noted, and exposed in the east face of the pit are the following:

		INCHES.
3.	Sand	12-18
2.	Glacial till	12-18
1.	Sand	6

These three members have a strike similar to that of the horizons below, but dip in the opposite direction (northeast) at an angle of about 50° (figure 49). The till horizon thins to left and right, forming in the pit face a lens-shaped exposure about fifteen feet long. It may be either a mass of till put down upon the large gravel mass or the thinning edge of the surrounding till which appears partly to inclose the gravel mass. If the gravel were entirely worked out the contacts might throw much light on the relation of the gravel masses and the till. Above these three members in the pit face is a jumbled mass of pebbles, bowlders and clay material three to four feet thick and then a sandy, pebbly soil horizon of two feet.

Just south of the northwest corner of section 22 is a large pit in a gravel hill on the south slope of the valley. This is the largest of these hills along this creek and rises forty feet above the stream, although its top is only slightly higher than the upland just to the south. The material here is somewhat coarser than in the last pit described. Clay-balls are quite abundant in some zones and averaged 20 per cent in three analyses. They range in size from small pebbles to masses six to eight inches across. The material is stratified and the horizons are inclined with a strike N. 40°-50° W., and a dip of about 20° SW. The following section is exposed in this pit.

		FEET.
10.	Gravelly soil	1½
9.	Alternating layers of sand and gravel	3
8.	Coarse reddish gravel	2½
7.	Fine cross-bedded sand	3
6.	Coarse gravel or pebble horizon. Contains numerous clay-balls ranging in diameter from 1 to 8 inches. This horizon is variable. At the east end of the pit it contains a 4 foot layer of fine cross bedded sand, which thins out entirely in 40 feet to the west. At the central part of the pit face it is very bowldery. At the west end it is fine gravel with a few pebble layers	15±
5.	Poorly exposed coarse sand and fine gravel. Some of the gravel layers are moderately rusted	15
4.	Fine sand with delicate lamination and cross-bedding. Horizontally this grades into coarse sand not distinguishable from No. 3	1½
3.	Cross-bedded grayish sand with a large percentage of grains of shale. Some layers are so largely of shale that they are sticky like clay when moist	2½
2.	Coarse reddish cross-bedded sand containing clay-balls in upper part. Only partly exposed	8
1.	Poorly exposed fine yellow-gray sand	10

In the north part of section 21, and the south parts of sections 16 and 17, farther down Willow creek valley, there are more of these hills, several of which show shallow exposures of gravel. In the southeast quarter of section 17 a small abandoned pit in one of these hills (figure 50) showed gravel containing 59 per cent of clay-balls.

Northern Cherokee County.—Near the south line of section 10, Cedar township, Cherokee county, a mile north of Larabee, there is a gravel hill that has been worked for a number of years. It is located on a divide and stands ten to fifteen feet above its surroundings. Another hill about half a mile to the north is of similar size. The pit exposure in the first hill shows relatively fresh coarse gravel in inclined layers. Clay-balls are plentiful and some are as much as six inches in diameter, and the pit face showed a lens of till five feet long and four to eight inches thick. This hill was mentioned by Professor Macbride in his report on Cherokee and Buena Vista counties, and was interpreted as being "part of a continuous series of such deposits extending from Sibley south and east, including the gravel pit at Sheldon and similar deposits about Calumet."[49] The deposits at Sibley and Sheldon are valley deposits, while the "deposits about Calumet" probably refers to the gravel hills along the headwaters of Willow creek described above. The suggested "continuous series of deposits extending from Sibley south and east" does not exist, although there are several points to suggest such a series.

One mile south of Larabee, on the east side of the railway, at the center of the northwest quarter of section 26, an abandoned pit in one of these hills shows a rather rusty gravel with many clay-balls. In the north half of the southwest quarter of section 34 are several hills, one of which has an exposure showing the usual light-colored gravel with clay-balls.

Southeastern Cherokee County.—In southeastern Cherokee county there are gravel hills at many places in Pitcher and Diamond townships. They are most numerous along a ridge which extends from the northwest quarter of section

[49]Iowa Geol. Surv., Vol. XII, p. 322. 1902.

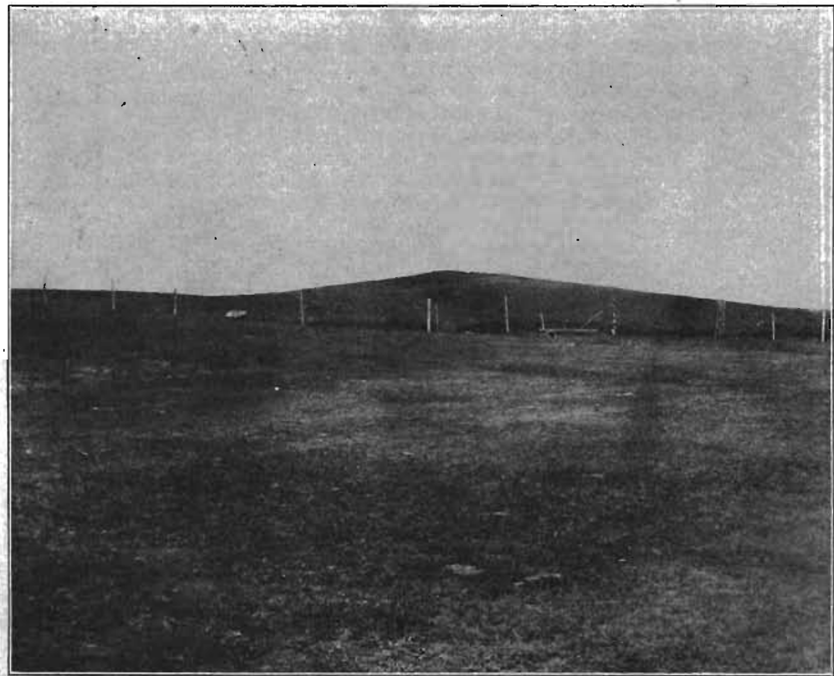


FIG. 50. Gravel hill on the north slope of Willow creek valley in the southeast quarter of section 17, Liberty township, O'Brien county.

28, Pitcher township, southeast across this section and south through the east part of section 33. Pebbly mounds appear on this ridge just northwest of the center of section 28, in the southwest quarter of section 28, at the northeast corner of section 33, and at a number of places in the east part of section 33. A group of hills near the quarter-corner on the east line of section 33 have been worked for sand for many years. There are other pebbly hills near the center of section 21, and in the northwest quarters of sections 22 and 9. The pebbles, as exposed at the surface of the mounds, show only the hardest varieties of rock, but in the pits and road-cuts on the east line of section 33 all the usual kinds of pebbles are present, with some clay-balls. The material in general is more ferruginous than is common farther north, but in the pits just noted there is much fresh fine-grained sand. Gravel hills containing very ferruginous sand appear also in the east part of section 4, Diamond township.

In the northeast quarter of section 35, Diamond township, there is a group of gravel hills which extend also into the adjoining corners of sections 26 and 25 (Plate XV). The shallow exposures in this group of hills show greatly altered material with rotted igneous pebbles and limestone pebbles altered to clay ironstones, but some deeper exposures in gravel pits show fresh gravel and sand. In the northeast part of section 25 there is an isolated, steep-sided, kamelike hill on the south slope of Little Maple river valley.

The great alteration of the gravel of many of the gravel hills of Diamond township raises the question whether they are of the same age as the hills farther north. Their position would make them the same but the material in the upper part of some of them looks older. However, alteration is not merely a matter of age. The more frequent the alternation of the presence of water and air in the gravel, the more rapid the alteration. Neither water nor air remaining permanently in a deposit will produce much change. The hills of section 35 are in a region of considerable relief where there would be fairly rapid motion of the ground-water and notable fluctuation of the ground-water table with each successive period of rain. Under these conditions alteration would be more rapid than in the more level regions farther north.

Northeastern Ida County.—In northeastern Ida county, on the northeast quarter of section 15 and the southeast quarter of section 10, Galva township, there is a group of low mounds with pebbly surfaces, of which one on the section line has an exposure showing a ferruginous dirty gravel with clay-balls. Other low mounds with pebbly surfaces are located in the northeast quarter of section 24, where a dozen or more low swells show pebbles; in the northwest quarter of section 12; the north half of section 23; the northwest quarter of section 25; and in Silver Creek township to the south, in sections 9 and 8, on the slope of Silver creek valley.

Sac County.—Just southeast of Early in the northcentral part of Sac county, only one to three miles from the Wisconsin drift-boundary, gravel hills with pit exposures are found in the southwest and northeast quarters of section 10, Boyer Valley township. The surface of the hill at Early on which the water tank is located is pebbly and five miles south of Early a low gravel hill is located just east of the southwest corner of section 34. The material seen in the pits at the southwest corner of section 10 consists of iron-stained gravel and fresher cross-bedded sand. The coarse-grained igneous pebbles and bowlders are much decomposed, and even some of the limestone pebbles are altered. In his report on Sac and Ida counties, Professor Macbride mentions gravel deposits in and about Early;[50] gives pit sections from both the gravel hills of section 10; and shows gravel pits on the Sac county map in section 10 southeast of Early and in section 31 west of Lake View. Concerning these gravel deposits he says they "represent probably an overwash from the drainage of the Wisconsin front." All these hills are well up toward the top of the divide between Boyer river and Indian creek, a mile to two miles west of the Wisconsin drift-margin, which lies along Indian creek valley (page 258). Kansan drift topography intervenes between this drift margin and the gravel hills, and there is no evidence that the Wisconsin ice occupied any part of the area west of Indian creek, or drained across this divide. The topographic position of the hills and their isolation from the Wisconsin drift-margin show that the material was not derived from the Wisconsin ice margin.

One mile north of Wall Lake, in the central part of section 1, Levey township, there is a group of gravel hills, covering fifteen to twenty acres, which have been extensively worked for a number of years for road ballast. The material here is light-colored gravel with a high percentage of limestone pebbles and is much fresher than most of the material of the gravel hills south of Cherokee. In one of the pits there is much light yellow siltlike material

[50]Iowa Geol. Surv., Vol. XVI, p. 540, 1906.

mixed with the gravel. Gravel hills are frequent also along the west line of section 1, Levey township, and in Clinton township, in the northeast quarter of section 32, the northwest quarter of section 35 and the southwest and northeast quarters of section 26.

South of Wall lake outlet, in the north part of the southwest quarter of section 19, Levey township, a pit on a valley slope exposes a fine gravel with much limestone. Clay-balls are abundant and the material is evidently of the gravel hill type. Gravelly swells are found also near the quarter corner on the south of this section. In the northeast quarter of the southwest quarter of section 20 there is a gravel pit in a shoulder on the east slope of the valley that forms the Wisconsin drift-boundary. The material is a dirty gravel containing many clay-balls and masses of till. This appears to be one of the gravel hills of the Kansan drift-region although the surface just to the east shows Wisconsin drift topography.

ORIGIN OF THE GRAVEL HILLS.

Evidence of Structure.—Most of the gravel is stratified, and many of the individual layers are themselves beautifully cross-bedded and finely laminated. Most of the deposits that are adequately exposed show the layers inclined at a considerable angle. In the pits just northwest of Calumet the gravel layers have an inclination of 58°, while some of the cross-laminae are inclined as much as 70° (figure 48). Other masses showing tilted layers are found in section 10, one mile north of Larabee, and in the southwest quarter of section 36, three miles south of Adrian, Minnesota, where cross-laminæ have an angle of 80° (page 364). These angles are well above the highest possible angle of deposition, and the strata have come into their present position by a tilting of the mass since the deposition of the gravel. The strike and dip of the beds in most cases are uniform in a particular gravel hill, indicating that the tilting affected the gravel mass as a unit.

Evidence of Location.—Most of the gravel hills are located along valleys or on the slopes of valleys. The most notable instance of their location along valleys is along Willow creek, west of Calumet, in southern O'Brien county, but other examples were noted in northern Franklin township of O'Brien county; five miles west of Sibley; and three miles south of Adrian, Minnesota. The pronounced development of these hills north and northwest of Little Rock (page 363) is within or on the slopes of Little Rock river valley. From the valleys, these hills may appear prominent but their tops are seldom higher than the upland, and from the upland they are hardly recognizable. Some of the hills are located on divides.

Evidence of Material.—One of the characteristics of these gravels is the presence of the clay-balls seen in most of the exposures. Balls of clay, even when frozen, cannot be supposed to have withstood the wear of transportation by running water for a very long time, and these clay-balls, therefore, indicate that the material was not carried great distances before deposition. The large percentage of shale and other soft materials found in some of the exposures and the prevalent subangular form of the pebbles, point to the same conclusion.

The clay composing the clay-balls is typical Kansan till, and therefore the gravel containing them cannot be older than the Kansan ice-sheet. But the gravel containing the clay-balls is at many places partly inclosed in Kansan till, and there seems to be no division between these masses and those completely inclosed in the till, and which likewise contain clay-balls. The deposit cannot, therefore, be younger than the Kansan ice-sheet.

In general appearance these gravels look very much like the gravel masses included in the till, like the gravel interbedded with the till, and like the valley gravels. The pebbles of the gravel are very much like those of the Kansan till, and from its general appearance the gravel might have been derived from this till.

Conclusions.—As has been noted these gravel hills have the form of kames and one hypothesis as to their origin is that they are kames formed during the retreat of the Kansan ice-sheet. However, the surfaces upon which these hills stand are not constructional but erosion formed, and as is shown elsewhere (page 332) there is reason to believe that the entire surface is below the original Kansan drift-plain. Also the uniformity of strike and dip throughout one of the hills, the distinctly bedded character of the material, and the well developed lamination and cross-bedding show a regularity too great for kame deposits.

The evidence of structure and material noted above links these gravel hill with the inclosed gravel masses. They differ from the gravel masses only in being at the surface instead of beneath the surface. They are interpreted as gravel masses which were formerly inclosed in the Kansan till, but by the erosion of the overlying till they have been brought to the surface. They are within and on the slopes of valleys where erosion is most rapid. They stand as mounds upon the slopes because the gravel is more resistant to erosion than the till, and they have slowly become elevations by the removal of the inclosing till just as a resistant rock material comes to stand above its surroundings by the greater erosion of the surrounding area. Gravel erodes more slowly than till because it is more porous and there is greater percolation into the gravel and less surface drainage.

The gravel masses originated in the same way as explained for the inclosed gravel masses (page 361). That is they are fragments of a deposit formed in front of the advancing ice-sheet which a little later plowed up the deposit and incorporated frozen masses of gravel in its drift. These masses were tilted into various positions so that the originally horizontal bedding is now inclined at various angles.

Interbedded Gravel and Till.

Exposures showing till interbedded with sand and gravel were seen at a number of places within the Kansan area, especially in northern Cherokee county. The sand and gravel are mostly fresh and the latter is mostly fine. Coarse sand with pebbles scattered through it is common. Some of it is distinctly bedded and some shows no stratification. Locally the gravel is cemented by a calcareous cement and so forms irregular masses of firm conglomerate; or cementation may affect the whole or part of a stratum over a considerable area. Cementation is more common at the top of the gravel zones than at the base, and apparently is more common on the face of an exposure than farther back from it.

DISTRIBUTION AND DESCRIPTION OF EXPOSURES.

By far the greatest example of the interbedding of gravel and till observed, is that found in the east bluff of Mill creek in the west half of section 14, Cherokee township, three miles north of Cherokee. Mill creek, at this place, flows against the base of the east slope of its valley, and this slope rises very steeply 100 to 120 feet to the crest of a narrow ridge which overlooks the valley of Mill creek on the west and the Little Sioux valley on the east. The good exposures are just south and north of the line through the center of section 14, distributed through a distance of about eighty rods, and are found in little gullies and slides that give exposures of the underlying material. The lower thirty to forty feet of the valley slope is gentle but shows a few exposures of the typical Kansan till. Above this is a steep slope of seventy-five to a hundred feet, consisting of about equal parts of interbedded till and gravel which alternate several times in the vertical section. The gravel horizons vary in thickness from mere seams to twenty feet, but a common thickness is ten to fifteen feet.

Most of the gravel is fresh and has a light color due to the predominance of gray limestone pebbles. It contains many clay-ball pebbles from the associated Kansan till, and some of Nebraskan till. The interbedding of gravel and till and the presence of the clay-balls of the associated till in the gravel, show that the gravel belongs to the same stage as the till. The general appearance and composition of the pebbles also indicate that they were derived from this till.

These exposures in the Mill creek bluff of section 14 are such good ones that the following sections are given, recording in detail the succession found in several of the better exposures. The exposures are all mere gully washes and are partly obscured by slumping and surface accumulation. The sections are given in order from south to north.

Section A.—If approach is made from the south, the first exposure that is seen that covers approximately all of the height of the slope, is thirty to forty rods south of the quarter-section line. This exposure is shown diagrammatically in A of figure 51.

		FEET.
11.	Grass-covered gravelly clay slope rising to the top of the ridge, which is here 106 feet above the creek. Probably till, but it may contain some gravel layers	12
10.	Light brownish gray till with pebbles and cobbles.... The exposure is not entirely continuous and the division may contain some gravel. Numbers 11 and 10 combined would make a till zone 30 feet thick, which is greater than for any single zone of till known along this bluff. There is also the unexposed zone (9) below, which may be largely till. It is not probable that numbers 11, 10 and 9 form a single continuous till zone or even that numbers 10 and 11 are without a single gravel layer.	18
9.	Unexposed slope	10

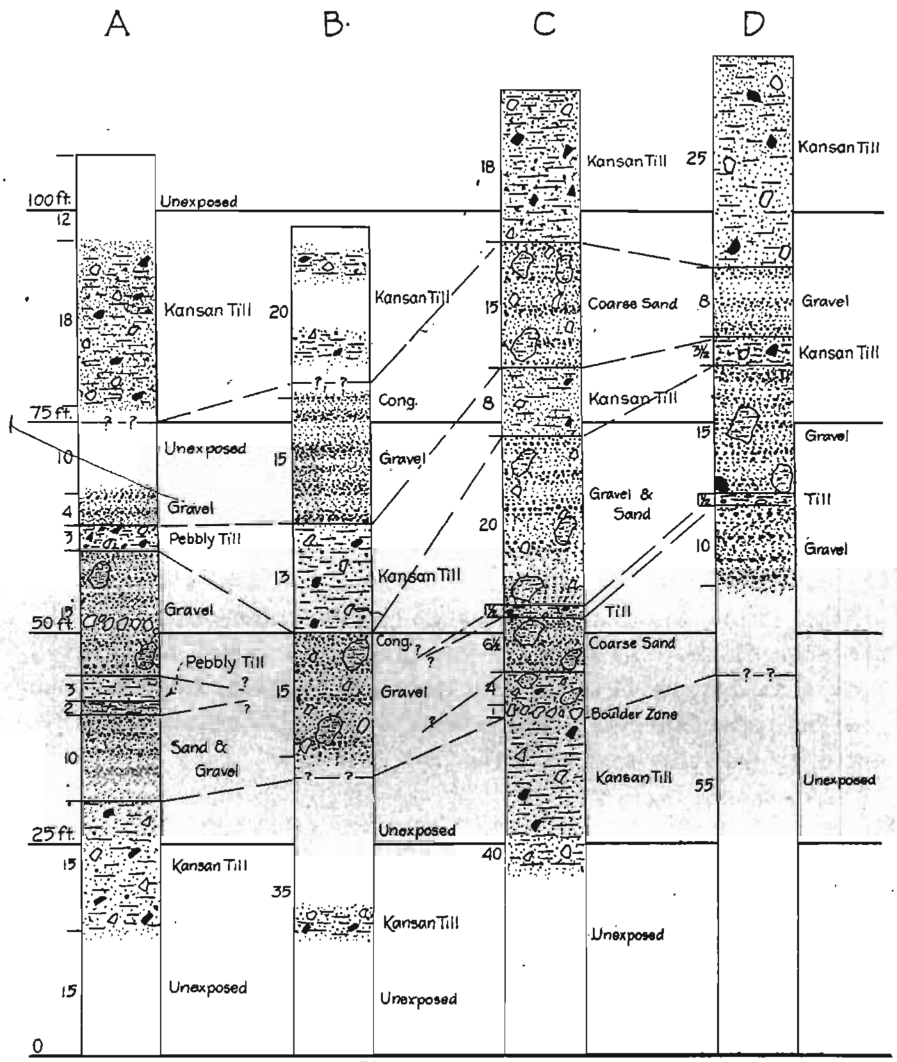


FIG. 51. Columnar sections of exposures in the east bluff of Mill creek in the west half of section 14, Cherokee township. The probable correlation of the numbers of the several sections is indicated.

8.	Light-colored gravel................................	4
7.	Light brownish gray till with pebbles, cobbles and small ocherous masses. In some places the pebbles and cobbles make up fully half of the whole. The basal contact on the gravel is very sharp, without any alteration or deformation of the gravel.......	3
6.	Gravel with large pebbles and bowlders scattered through it and a layer of bowlders about 5 feet above the base. Many included clay-balls and	

masses of till are present. The gravel has a light color and limestone is the dominant material. Shale pebbles are quite abundant. This is the typical gravel associated with the fresh till.......... 15

5. Brownish yellow till which breaks into elongate chunks 3
4. Brownish blue-gray sandy till. In the line of section it is 8 inches thick, but it thickens abruptly to the north, being 2 feet thick only 3 feet away. This may be a lens of till........................ ⅔—2
3. Sand and gravel; at top a fine yellow sand; only partly exposed 10
2. Slope with several exposures of oxidized brownish yellow Kansan till 15
1. Unexposed slope to creek level..................... 15

This section gives at least three gravel zones and four till zones, and a better exposed section probably would increase the number.

Section B.—The gully just north of the quarter section line fence exposes the following, beginning ninety-eight feet above the creek and passing downward. The columnar section is shown in B of figure 51.

FEET.

5. A pebbly clay slope with a few exposures of brownish gray till 20
4. Gravel horizon; cemented to a conglomerate near the top 15
3. Brownish yellow-gray till; harder and more compact than number 5. Where it is fresh it breaks into irregular chunks and crumbles to a sandy clay. The lower 3 feet includes much gravel.............. 13
2. Light-colored gravel with pebbles, cobbles, clay-balls, and some larger masses of till 15
   In the gully the upper 2 feet of this horizon is cemented, forming a calcareous conglomerate, but this does not continue horizontally beyond the gully. The lower part of the slope is so badly slumped that the lower contact of the gravel could not be exposed
1. Unexposed to creek level, except for one small outcrop of oxidized, brown Kansan till at 15 feet above the creek 35

This section shows two distinct layers of fresh gravel, each at least fifteen feet thick, and each overlain by Kansan till. A cemented zone is found at the top of each gravel layer. The cementing material is calcareous and the cementation is sufficient to make firm conglomerate, large blocks of which lie on the slope below the outcrop. The cemented parts differ in thickness and seem to be irregular, cemented masses rather than continuous beds. This cementation is due to the evaporation which takes place when ground water percolating downward passes from the compact till to the porous gravel. If the water has become saturated with calcareous material, this evaporation will cause deposition. The air within the gravel horizon is frequently in motion in order to equalize air pressure within the gravel mass with the changing atmospheric pressure outside, and this favors evaporation by preventing the air from becoming saturated with moisture. The greatest motion of the air within the gravel zone would be at the top, and near the face of the exposure, and in these places the greatest cementation is found.

Section C.—This exposure is in a gully about forty rods north of the quarter-section line fence. It is shown in C of figure 51.

		FEET.
9.	Gravelly clay slope	18
8.	Ferruginous coarse sand with pebbles, cobbles and clay-masses	15
7.	Sandy brownish gray till which breaks out in irregular chunks and pulverizes to a sandy clay	8
6.	Ferruginous gravel or coarse sand with pebbles, cobbles and numerous large clay-masses, some of which are 2 to 4 feet across	20
5.	Bluish gray till with brown streaking along joints	1½
4.	Coarse sand with pebbles, a few cobbles and clay-balls. The lower 18 inches is about half clay in the form of clay-balls	6½
3.	Yellowish brown till with many pebbles and pockets and seams of sand	4
2.	Coarse gravel with cobbles and bowlders	1±
1.	Brown Kansan till was exposed for 18 inches below the top of the layer and at one point 10 feet lower. Remainder of division to creek level unexposed	40

Section D.—At the place where the bluff begins to bend to the west there is a gully which branches about fifty feet above the creek. The following exposure was seen in the north branch of this gully. It is represented in D of figure 51.

		FEET.
7.	Pebbly clay slope rising to the crest at 118 feet above the creek	25
6.	Gravel with clay-balls	8
5.	Brownish gray till	3½
4.	Gravel with cobbles and clay-masses	15
3.	Brownish yellow plastic sandy till	1½
2.	Gravel with clay-masses	10
1.	Unexposed to water level	55

Several other exposures to the north show a part of the section and in every case where more than a few feet is exposed an alternation of gravel and till is to be seen.

The beds of all these gullies are filled with bowlders. Pink and gray granite of the fine-grained type predominate, but basalts are numerous and limestones are more prominent than is common among bowlders.

The sections given above show two, three and four gravel horizons, and few of the exposures were continuous enough to demonstrate that other thin gravel layers are not present. Some similarities of sections which are very close together were noted, but on the whole it appears that the individual horizons are not continuous throughout the length of the bluff. Figure 51 shows such correlations as can be made between the various members of the several sections.

The till interbedded with gravel in the upper parts of these exposures is less oxidized and appears fresher than the till exposed in the lower thirty or forty feet of the bluff where gravel is not found. In the lower ends of several of the gullies toward the north end of this bluff, the Nebraskan drift is exposed (page 422).

At several places in the exposures described above the interbedded gravel contains such a great number of clay-balls that they constitute a very important part of the whole. These clay-balls indicate that the material had not been carried far before deposition, for clay material could not have withstood the wear incident to long transportation, even though it was firmly frozen. As the clay-balls were formed probably near the edge of the ice-sheet, their presence indicates the nearness of the ice-front at the time of gravel deposition.

The banks of the creek valley in section 24 of Cedar township, Cherokee county, east of Larabee, show a number of small exposures with gravel and sand associated with the till. Examples appear a few rods to the north and to the south of the east-west quarter-section line. Farther down the creek valley, exposures of gravel, sand and silt associated with till may be seen at a number of places. Some of these gravels evidently are included masses, while others may be gravel beds of some extent. A conglomerate ledge projects at one place, and elsewhere masses of conglomerate lie on the surface. The valley slopes are quite completely grassed over but if good exposures existed, the section might be somewhat similar to that of the Mill creek bluffs described above.

A peculiar case of interbedding of gravel and till or really of inclosure of a layer of till in a great gravel deposit is exposed in the pits of the Cherokee Sand and Gravel Company about half a mile northeast of the Mill creek bluffs just described. These pits are located in the northeast quarter of the northeast quarter of section 14, on a terrace of the Little Sioux valley about seventy-five feet above the river. Several pits have been worked in the past on the slopes of a ravine that cuts into the terrace, but at present a single pit is operated on the terrace and in this the gravel is removed to a depth of fifty to sixty feet. All the pits show essentially the same succession. At the top is a gravel bed a few feet thick; then a layer of till four to seven feet thick; and below this is the great gravel layer.

Three abandoned pits each seventy-five to a hundred yards from the others, are located on the slopes of the ravines as shown in figure 52. The till layers of the three exposures are of practically identical material, are at approximately the same

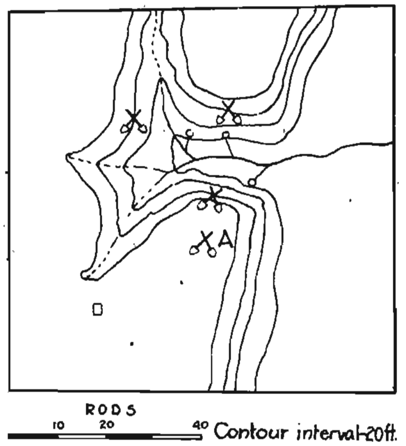


FIG. 52. Sketched contour map showing the location of gravel pits on the farm of F. R. Turner (northwest quarter of the northeast quarter of section 14, Cherokee township). The pit *A* is now operated by the Cherokee Sand and Gravel company.

altitude and have the same thickness, so that there is little doubt that the till was once continuous across the intervening valleys over an area at least 100 yards across. The mass is too large to have been floated in by ice and must have been laid directly by the ice-sheet. The till bed is thinner in the pit on the terrace just south of the ravine and is said to be absent beneath the terrace a few rods farther south.

The till of this horizon has a brownish gray color with iron staining along the joints. It is the fresher phase of the Kansan till, the type commonly found in association with gravel.

The position of this gravel beneath the bench of the Little Sioux valley would seem to prove that it belongs to the valley gravels but the presence of the clay-balls and this great mass of till indicate that the gravel was deposited during the Kansan ice-epoch.

A cut on Spruce street, just east of Second street, in the north part of Cherokee, within the area of the higher bench level, shows a great diversity of material including gravel, sand, bowlders and till layers. There are many alternations of the material horizontally and vertically. The gravel is coarse, dirty, and contains many large bowlders. Clay-balls are abundant, and in some horizons there is only a little gravel as matrix between the large clay masses. One bed appeared to be till, but when it was dug into, the material separated into rounded masses of till which are packed together without matrix. Also there are lenses or layers of till, too large to have been floated in, which must have been deposited directly by the ice. The upper seven or eight feet of the cut shows the more common valley gravels overlain by loess.

At various other places, examples of gravel layers interbedded with the till were seen, which indicates that the phenomenon may have a rather general distribution, but nowhere else are the interbedded layers known to be so numerous as in the Mill creek bluffs north of Cherokee.

ORIGIN.

The advance of the edge of an ice-sheet probably is really a succession of advances and retreats in which the advances are greater than the retreats. Likewise the general period of retreat of the ice-edge may be broken by temporary advances. Between these two general periods there is a longer or shorter time when the oscillations approximately balance each other, and the general position of the ice-edge remains nearly constant. These oscillations may be due to seasonal changes or to changes taking place over a longer period. Gravel deposited beyond the front of the advancing ice-sheet soon may be overridden by the ice, and covered with a deposit of till. If now the ice-edge withdraws temporarily, gravel may be deposited on top of the till only recently laid down. Readvance of the ice would result in a second till horizon, and so with several oscillations several alternations of till and gravel might be formed. It is not necessary to assume any great oscillations of the ice-front, for none of the gravel horizons noted above has been shown to cover any considerable area. An oscillation of a fraction of a mile, or a few miles at most, would be adequate.

Gravel deposited near the edge of the ice, in the way just outlined, would be of the outwash type, consisting of fresh, unweathered material with some pebbles of soft rocks, and would rest on fresh till. The gravel of these horizons is therefore interpreted as having been deposited just beyond the front of the ice-sheet during the minor oscillations within the stages of advance and retreat.

CHAPTER V

THE VALLEY GRAVELS.

Gravel deposits exist along many of the stream courses of northwestern Iowa. They are found in both large and small valleys; even in mere swales on the upland near the heads of small creeks. These deposits occupy broad, shallow valleys; are in most cases of only moderate thickness; and thin out toward the sides of the valleys. As a rule the present stream channels are cut into the gravel fillings, while the parts which remain form terraces which differ greatly in height, some of them being as much as 100 feet above the streams.

Nature of the Gravels.

The material is mostly coarse sand and fine gravel, and the extremes in either direction, coarse gravel or silty sand, are rare. The material is horizontally bedded, but not well assorted and the layers in most cases are ten to twelve inches thick rather than thin beds. Some of the layers are cross-bedded, with lens and basin structures. Another common condition, especially along small valleys, is thick layers of sand with small pebbles up to one or two inches in diameter scattered through it.

The material is distinctly fresh and commonly is without the least indication of iron-rusting or other alteration. Much of the sand, 70 to 80 per cent of the whole, is of pure quartz. Among the pebbles there are many kinds of rocks, but gray limestone pebbles are most abundant and give to the whole deposit a light color. The average of eighty-one analyses of pebbles from the valley gravels gives: Igneous rocks 36 per cent, of which 21 per cent are granite; and sedimentary rocks 64 per cent, of which 57 per cent are limestone. The percentage of the igneous and other resistant kinds of pebbles is larger down the valleys and to the west and southwest. In comparison with the material of the gravel hills, these valley gravels contain 11 per cent more of igneous rocks. This is perhaps the result of the destruction of the clay-balls and shale pebbles and a consequent relative increase of other kinds. The number of limestone pebbles worn out largely offsets the relative increase due to the destruction of the clay-balls, so that most of the increase is in the igneous rock pebbles.

Distribution and Description of the Valley Gravels.

Valley gravels are found along the larger rivers, along the medium-sized streams, along the small creeks even nearly to their heads on the uplands, and they fill in certain broad areas on the headwaters of some of the streams. Their distribution evidently is independent of the size of the valley.

Several of the larger rivers head northeastward within or along the Wisconsin drift-margin, and therefore may have carried drainage from the Wisconsin ice. This is true of Big Sioux, Rock, Little Sioux and Boyer rivers. The drainage basins of Floyd and Maple rivers, however, are entirely beyond the margin of the Wisconsin ice. Also many of the tributaries of those stream valleys which contain Wisconsin gravels, are entirely beyond the margin of the Wisconsin ice.

THE BIG SIOUX RIVER DRAINAGE BASIN.

THE MAIN VALLEY.

Big Sioux river drained the east margin of the Dakota lobe of ice of the Wisconsin epoch from the head of the Coteau des Prairies southward to Canton, and received through its larger tributaries drainage from the west margin of the Des Moines lobe. The valley contains a gravel deposit south of the northwest corner of Iowa and at several places this deposit forms prominent terraces.

Near the northwest corner of the state, west and northwest of Granite (Plate XV), there is a terrace area two miles long and one-half to three-quarters of a mile wide (Granite terrace). The surface altitude is 1330 to 1345 feet above sea level, or eighty to ninety feet above the river. At the south end of the bridge on the west line of section 19 just west of Granite, the terrace gravel is twenty feet deep, and rests on Kansan till which continues down to the creek level, twenty to twenty-five feet lower. The north slope of the valley at this place shows twenty to twenty-five feet of fresh gravel and sand in the terrace. About a mile west of Granite in the northwest quarter of section 24, the Chicago, Rock Island and Pacific Railway Company operates a gravel pit in the terrace. The following section is exposed in the pit and in a gully below.

		FEET.
4.	Soil, etc	3
3.	Bowlder bed, badly iron-rusted and partly cemented. The coarse-grained bowlders of igneous rock are rotted, and the limestones are decayed to brown masses	4
2.	Relatively fresh gravel and sand	16
1.	Kansan till. Continuous exposure for 5 feet and at intervals for 30 feet	35

The gravel horizon in the two exposures noted has a thickness of about twenty feet, but these exposures are located along the continuation of Blood Run valley across the terrace, and the average thickness of the deposit over the whole area is probably less.

South of Blood Run the terrace continues as a narrower belt across sections 26 and 35 and is terminated by an eastward bend of the river just south of the township line. It begins again in section 7, Centennial township, and with a width of about a mile continues south to Klondike (Klondike terrace). The Klondike terrace is only forty-five to fifty-five feet above the river or thirty to forty feet lower than the Granite terrace. The material was seen just east of the bridge at Klondike, where it is a coarse gravelly deposit, and in the north part of section 17, where it is largely coarse gravel with bowlders, and is partly cemented. In the latter exposure the gravel rests on a tough dark drift which Professor Shimek has interpreted as "probable Nebraskan"[52].

From Klondike south to Canton the river follows the Iowa bluff, and the Dakota side, although rising gradually, does not present a distinct terrace. Along this portion of the Big Sioux valley the Dakota lobe of ice pushed up to the river and such gravel deposits as exist are probably of Wisconsin age.

South of Canton, terraces appear at various places along the valley to Hawarden and Chatsworth. The river swings from side to side of the valley and the terraces are found here on one side and there on the other. The altitude of these benches is twenty to thirty feet above the river and is less southward.

Rock River Valley.

Rock river heads in northeastern Pipestone county, Minnesota, on the slope of the Coteau des Prairies. It enters Iowa at the center of the north line of Lyon county and flows southward and southwestward across Lyon and northwestern Sioux counties to Big Sioux river. Aided by its tributaries from the east it drained about fifty miles of the Wisconsin ice-margin and was therefore well located to receive gravel deposits of Wisconsin age. South of the state line the valley flat is about a mile wide, and much of this flat is a terrace about twenty-five feet above the river. Rock Rapids, Doon and Rock Valley are located on this terrace. At the mouth of Rock river valley the terrace unites with that of the Big Sioux, making a large level plain several miles across.

At Rock Rapids the gravel is twenty-five to thirty feet thick and rests on yellow Kansan till. A view of a pit about half a mile north of Rock Rapids showing cross-bedding and basin structure and variations in the coarseness of the material is shown in Plate XXI. At Doon the gravel deposits have been extensively worked in the past by the Great Northern Railway Company. A pit face here showed twenty-five feet of gravel, which was said to continue without

[52]Shimek. B., Pleistocene of Sioux Falls and Vicinity: Bull. Geol. Soc. Amer., Vol. 23, p. 144, 1912.

Lebatchka and Pattengill pit about half a mile north of Rock Rapids, Lyon county. The view shows cross-bedding and basin structure, variation in the coarseness of the material, and the thickness of the stripping. (Beyer, Iowa Geological Survey, volume XXIV, Plate XXXII, page 421.)

change for at least five feet below the pit bottom. At Rock Valley the town well is eighteen feet deep and is entirely in gravel, and the Chicago, Milwaukee and St. Paul Railway pit west of town has a depth of twenty feet, without reaching the base of the gravel. The material exposed at all these places along Rock river is fresh, and consists of sand and fine gravel with few cobbles or bowlders. Cross-bedding, inclined-bedding and basin structure are common.

TRIBUTARIES OF ROCK RIVER.

Area Northeast of Ellsworth, Minnesota.—East and northeast of Ellsworth, Minnesota, there is a slightly rolling area at the union of several small creeks. Gravel was seen in several shallow exposures where the roads cross the broad, saglike valleys, and north of Ellsworth there are pits four to six feet deep. This area is mapped on the Nobles county map of the Minnesota Geological Survey as "Modified Drift, Gravel and Sand"[53], but some of the area included is moderately rolling and certainly is not underlain with gravel. It is not an outwash plain completely covered with gravel, but an area with gravel along many of the small shallow valleys. The Wisconsin ice-margin lay about ten miles to the northeast, but the branches of Little Rock river and Kanaranzi creek completely prevented any drainage from the Wisconsin ice from reaching the Ellsworth area.

Little Rock River and Otter Creek.—Little Rock river, the principal tributary of Rock river from the east, heads in southern Nobles county, Minnesota, within and along the Wisconsin drift-margin, and therefore carried drainage from the margin of the Wisconsin ice-sheet. In Iowa it crosses the northwest corner of Osceola county and flows south and west across eastern Lyon county to its union with Rock river. There are gravel deposits along the valley at various places, forming indistinct benches which merge more or less gradually with the flood plain level which forms the major part of the area between the valley slopes. On the Lyon county map Professor Wilder showed this area as a Wisconsin gravel train with a width of about half a mile and extending continuously along the stream.

Just opposite Little Rock there is a low terrace with gravel exposures, and in the northeast part of the town is a small gravel pit. The material is horizontally bedded, and consists of fresh gravel and sand which is poorly assorted. The gravel of the pit is overlain by a two-foot layer of sandy, loesslike material which grades into the soil above. Although the valley may contain gravels of Wisconsin age, this and other deposits overlain by the loesslike material, along Little Rock river valley are older.

At George, ten miles below Little Rock, the terrace on the north side of the valley is almost half a mile wide and fifteen feet above the river. The south part of the village is on this terrace, and the town well, southeast of the railway station, has the following log.

		FEET.
4.	Soil	3
3.	Loesslike clay	7
2.	Gravel and sand, very fresh	12
1.	Yellow clay	?

Otter creek heads just within the Wisconsin drift-margin north of Bigelow, Minnesota, flows south along this margin for several miles and at the time of

[53]Upham, Warren, Geological and Natural History Survey of Minnesota, Vol. I, Pl. 22.

maximum glacial advance drained about ten miles of the ice margin. It has an irregular course southward across western Osceola county, and thence flows west and north in southeastern Lyon county to its union with Little Rock river southwest of George.

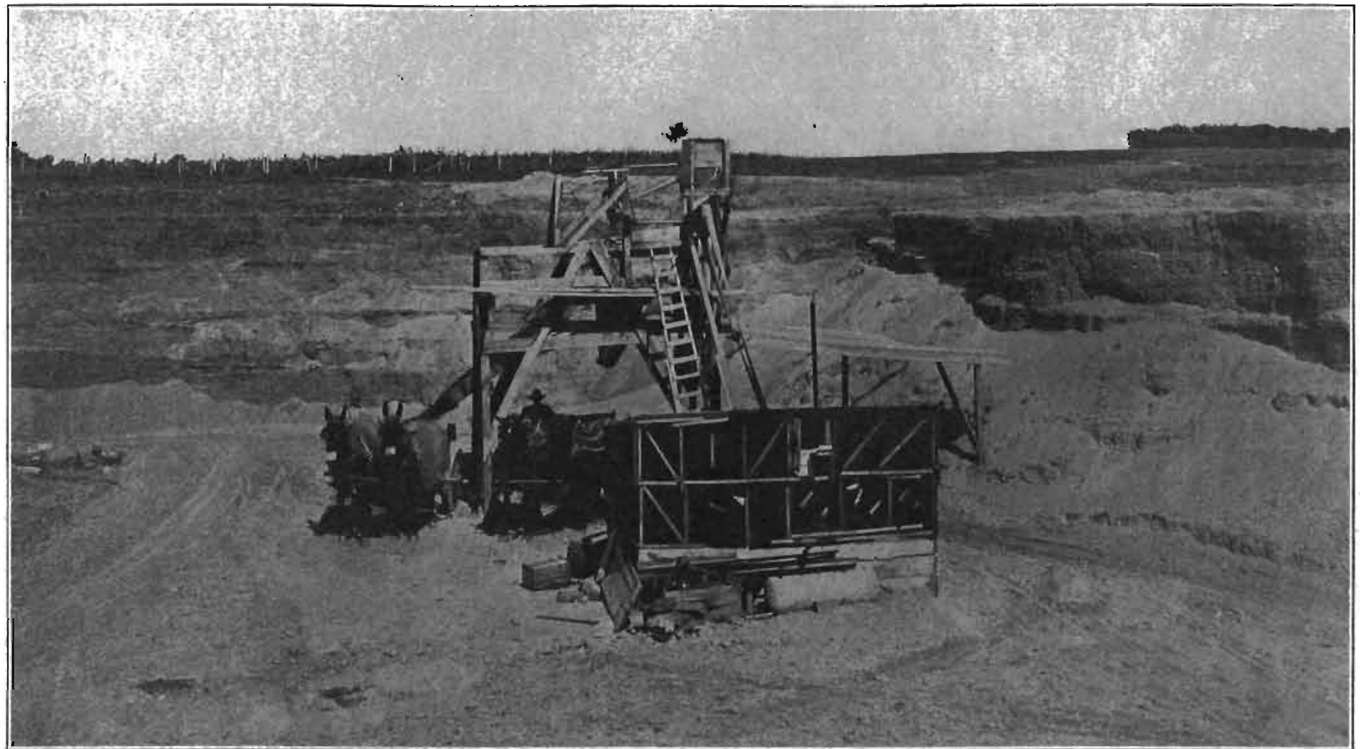
This valley has very little gravel in its upper course near the Wisconsin drift-margin, but from Gilman township in southwestern Osceola county across southeastern Lyon county gravel terraces are common. The material exposed in the terrace at Ashton is fresh, only the coarse-grained biotite granites being altered. An analysis of pebbles here showed the presence of 30 per cent of igneous rocks and 70 per cent of sedimentary rocks, 68 per cent of the latter being gray and buff limestones. On the county line northeast of Matlock, Otter creek valley is a broad shallow depression, with a broad flood plain and a narrower gravel terrace about fifteen feet above the stream.

Rat creek, a tributary of Otter creek in southeastern Lyon county, flows in a broad sag fifteen to twenty-five feet below the upland. The valley contains some gravel and indefinite low benches appear at several places. On the Lyon county map, Professor Wilder mapped a Wisconsin gravel train along the entire length of this creek. The valley is entirely beyond the Wisconsin drift-region and did not receive Wisconsin outwash.

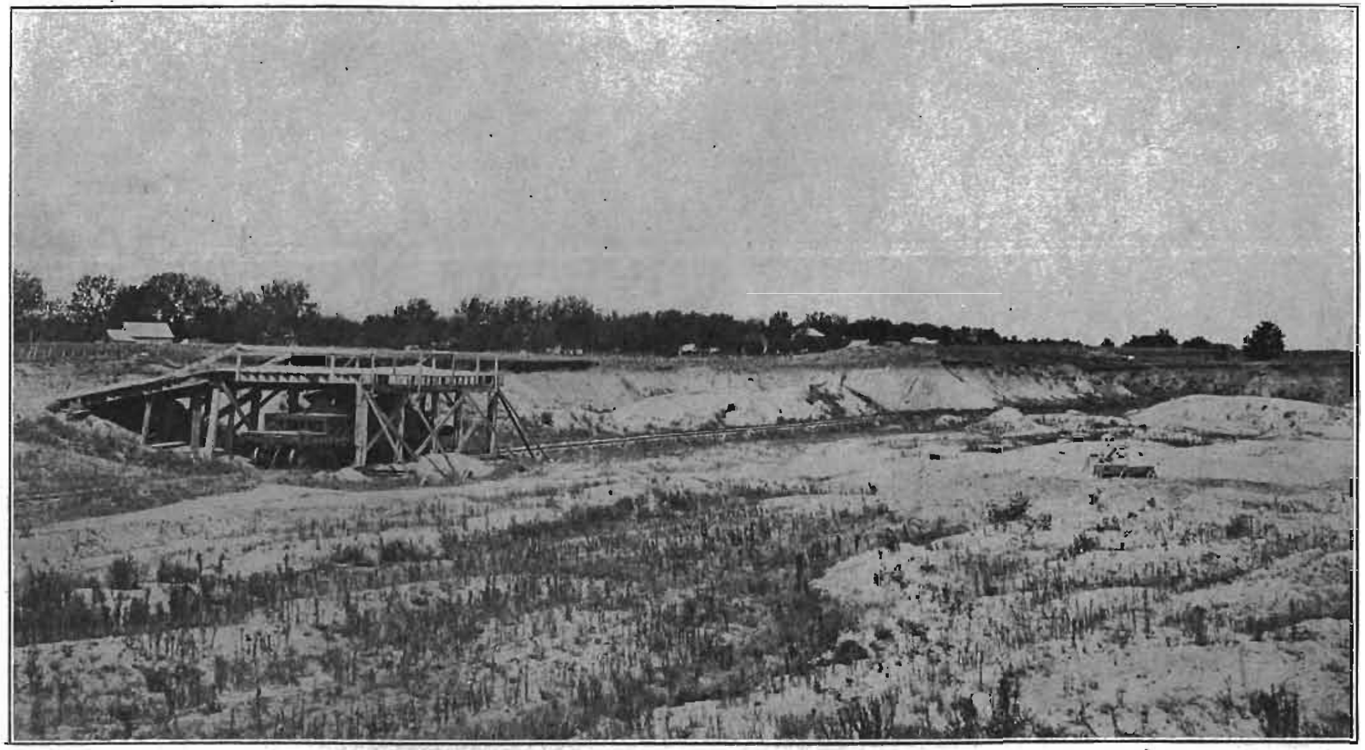
Area East and Southeast of Sibley.—At the edge of Sibley there are some large gravel pits in a deposit that is not along any present stream course. The deposit has an areal extent of eighty acres or more and underlies the east and south parts of Sibley. In the City pit (Plate XXII), twenty-five to thirty feet of gravel and sand were exposed, and the Chicago, Rock Island and Pacific Railway pit to the south (Plate XXIII) showed eighteen feet of gravel. The gravel rests on an uneven surface of fresh till, which at one place in the City pit slopes four feet in a horizontal distance of thirty feet, and greater irregularities are said to exist. Several mounds of till appear in that part of the railway pit from which the gravel has been removed. One of these, shown on the extreme right in Plate XXIII, consists of a mass of till with the gravel beneath it on at least one side, and in another the till has irregular contacts with the surrounding gravel, and may also be an included mass of till. The gravel of both pits is overlain by three to four feet of leached loess.

The gravel of these pits is, in general, fresh. At the top is a zone of coarse material, several feet thick, which is iron-stained, and near its base the gravel is in places stained a dark color. A well in this gravel area in the east part of Sibley stopped on a "cement rock" layer which is probably at the base of the gravel. Most of the dark coarse-grained igneous rock pebbles are decayed so as to crumble easily, limestone pebbles are abundant and unaltered, and many layers or laminæ contain a large percentage of grains of shale. The gravel is medium-grained and quite uniform. Bowlders are rare except at the base of the gravel, where they rest on the till. Several of these on the bottom of the pit are shown at the extreme left in Plate XXII.

A sewer pipe trench along the street just east of the City Park in the northeast part of Sibley was open in August, 1911, and showed at the south, sand and gravel overlain by loess. To the north fresh till rose above the level of the bottom of the ditch, the sand and gravel horizon thinned to zero, and the loess rested on the till. A sketch of this exposure is shown in figure 53. The exposure was apparently at the edge of the gravel deposit and showed the relation



City gravel pit at Sibley. This pit works twenty-five to thirty feet of gravel. The loesslike clay has been removed on the right. Its thickness, three to four feet, is shown in the center beyond the chute. (Beyer, Iowa Geological Survey, volume XXIV, p. 498.)



Chicago, Rock Island and Pacific Railway pit at Sibley. This pit shows fifteen to twenty feet of gravel and in most places has been worked to the underlying till. Mounds on this till surface or till masses in the gravel, which have been left behind in the process of excavation, are shown on the right at the far end of the pit. (Beyer, Iowa Geological Survey, volume XXIV, p. 499.)

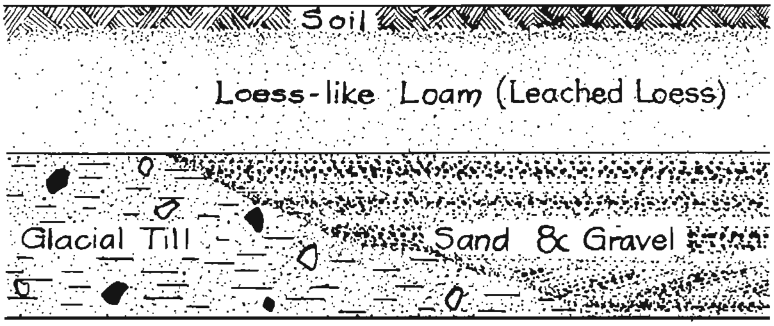


FIG. 53. Sketch of exposure in side of sewer pipe trench in the northeast part of Sibley. It shows the relation of the gravel horizon to the till, and of the loess to both the gravel and the till.

of the gravel to the till, and the relation of the loess to both the gravel and till. None of the contacts showed any alteration. Similar conditions were seen in an open trench along the north-south main street of Sibley at the street crossing near the Windsor Hotel (page 355).

Two miles southeast of Sibley, in the northeast quarter of section 30, East Holman township, a gravel pit, operated by the Chicago, Rock Island and Pacific Railway Company, exposed material similar to that at Sibley except that the upper part is coarser and more bowldery. Eighteen feet of gravel was exposed beneath a five foot zone of loesslike clay. A considerable area south of this pit in sections 30 and 29 is quite level, and is probably underlain with gravel. Sections 19 and 20 to the north, also are moderately level, but exposures in the gutter on the north of these sections show a yellow till.

The margin of the Wisconsin drift as traced by the writer is only a few miles to the northeast of these deposits east and southeast of Sibley, but the small valleys leading away from this Wisconsin drift-margin show no indication of having carried outwash material and the small valley of section 18, which passes near the deposit east of Sibley, did not head back to the margin of the Wisconsin ice. Also these deposits are overlain by loess which is older than the Wisconsin epoch. In appearance and composition these are the typical valley gravels of the Kansan drift-region.

Tom Creek.—This creek drains the northeast corner of Lyon county and enters Rock river at Rock Rapids. There are gravel terraces along its course and fresh gravel and sand may be seen in several valley pits in Midland township. A similar deposit is found along the north branch of Tom creek. Tom creek heads outside the Wisconsin drift-area and its gravel deposit is pre-Wisconsin in age.

Tom creek and Little Rock river drain the area in northeastern Lyon county mapped by Wilder as Wisconsin outwash (figure 27). Otter creek drains the similar outwash area in northwestern Osceola county. Although these areas have some gravel outside the present valleys, it is not sufficient to form an outwash plain. Several of the more important gravel deposits along these valleys are overlain with loess and probably essentially all of the gravel is of pre-Wisconsin age.

Mud Creek.—This creek heads in the southern part of Rock county, Minnesota, and flows south by southeast across Lyon county to Rock river near Doon. From the state line southward the valley is broad with gentle slopes and a flat bottom. This flat is, as a rule, a flood plain, but benches of gravel appear at many places. The altitude of the benches above the stream increases from ten feet near the state line to twenty-five feet near the mouth of the valley. The gravel is fresh and consists of relatively resistant material. Three analyses of pebbles from benches along this valley show an average content of 51 per cent of igneous rocks, which is 20 per cent higher than the average for pebbles from the valley gravels. The analyses also show a high percentage of quartzites and cherts, which are classed with the sedimentary pebbles. This valley is entirely within the Kansan drift-area and its gravels must be from reworked Kansan drift.

Small Tributaries of the Big Sioux.

None of the creeks considered under this heading are more than six to ten miles long and all lie entirely within the Kansan drift. The first of these south of the state line is Blood Run which flows southwestward across Sioux township in northwestern Lyon county, and joins the Big Sioux valley west of Granite. The Granite terrace of the Big Sioux valley (page 381) continues into the mouth of Blood Run valley as far as Granite, and gravel deposits appear to the east along the valley through sections 20, 21 and 22.

Plum creek enters the Big Sioux valley along the south edge of the Klondike terrace a few miles south of Blood Run. This creek was not followed, but Professor Beyer describes it as having a low indistinct terrace of small extent, and describes a pit exposure along the creek, three miles south of Larchwood, as showing seven to eight feet of clean sand and gravel resting on the blue clay.[64]

Dry creek and Six Mile creek, in western Sioux county, have broad, open valleys with narrow flood plains, and gravel deposits appear along them at various places, but nowhere do they form benches of any prominence. Similar gravel deposits are found along the creeks of western Plymouth county, especially along Broken Kettle creek, and in this region the gravel is overlain by a deposit which is unquestionably loess.

THE FLOYD RIVER DRAINAGE BASIN.

The Main Valley.

East of the Big Sioux lies the Floyd river basin. This is a smaller basin lying between the Big Sioux and the Little Sioux and is limited to the north by the spread of the basins of its larger neighbors. It heads in southern Osceola and northern O'Brien counties and flows south by southwest across eastern Sioux and central Plymouth counties to Missouri river at Sioux City. The Floyd drainage basin is separated from the Wisconsin drift-area by the high divide of southern Osceola county, and certainly received no drainage from the Wisconsin ice. However, the valley contains gravel from near its headwaters to LeMars, and probably to its mouth.

In northwestern O'Brien county there are small benches in the Floyd valley ten to twenty feet above the stream. Exposures in these benches are not

[64]Iowa Geol. Surv., Vol. XXIV, p. 426.

common, but one on the west side of the valley on the north line of section 21, Floyd township, showed three feet of horizontally bedded gravel overlain by about eighteen inches of leached loess.

About one mile north of Sheldon on the south side of the Floyd valley there are a large abandoned gravel pit and some smaller pits that are now being worked. In the abandoned pit west of the railway the following section was exposed.

		FEET.
3.	Black soil	1½
2.	Brownish yellow noncalcareous loesslike clay containing a few pebbles This member grades into the soil above, and in some places, by the inclusion of pebble bands, it grades into the gravel bed below. Although not true loess in the lithological sense, this material is certainly the time equivalent of the loess. Loess exists in the vicinity and rests on the till, as may be seen in a railway cut between these pits and Sheldon (page 354).	3-5
1.	Sand and gravel horizon This gravel is fine-grained with a few bowlderets, and some of the sand layers show inclined laminæ. The material of the layers changes horizontally in short distances so that any section taken fits only that particular place. The base was not exposed at the pit face but part of the floor of the pit is a cemented zone of cross-bedded sand.	10

In a small pit just north of the large abandoned pit, the gravel rests on fresh brownish yellow Kansan till, and there is no cemented zone at its base. A pit on the east side of the railway showed twelve feet of fine gravel. Several clay-balls (till) were found here, this being one of the few places where they were seen in the valley gravels.

South of Sheldon Floyd river has a broad, open valley with a gradually widening valley flat. Patches of terrace about ten feet above the flood plain exist at many places, and there are gravel pits in these terraces at Hospers, two miles north of Alton, at Alton, Seney and Le Mars (Plate XV). At the east end of the Chicago and North Western railway bridge at Alton some pits expose ten feet of gravel with thin layers of coarse sand, overlain by three feet of loesslike clay, which rises to an indistinct bench twenty feet above the river. Other pits in a bench of similar height north of the railway station show the same loesslike zone overlying the gravel.

A pit near the river in the northwest part of Le Mars showed the following section:[54a]

		FEET.
5.	Sandy black soil	4
4.	Loesslike clay, leached	3½
3.	Unleached loesslike clay with thin layers of sand The upper part of this zone contains small calcareous concretions.	6½
2.	Gravel	3
1.	Sand with thin layers of silty sand, exposed	3

The calcareous material removed by leaching from zone number 4 has been concentrated in the upper part of zone number 3 in the form of concretions.

[54a]This or a pit nearby was described and figured by H. F. Bain in his report on Plymouth county. Iowa Geol. Surv., Vol. VIII, p. 338 and Plate 29, figure 2.

These two zones are the time equivalent of the loess of the upland and together form a horizon much thicker here than farther up the Floyd vally at Sheldon. From the pit of B. Erdman just west of the above, several limb bones and pieces of deer horns have been taken.

South of Le Mars the flat of the Floyd valley is a mile to a mile and a half wide but it is all essentially at flood plain level. This flat is probably underlain with gravel.

Deep Creek Valley.

At Le Mars Floyd river is joined by Deep creek, which rises in southwestern O'Brien and southeastern Sioux counties, flows south to Remsen and thence west to Floyd river. Fresh sand and fine gravel appear in benches along this creek and exposures were seen in every section from Remsen to Le Mars. The gravel horizon is overlain by yellow loesslike clay, as in the Floyd river valley. In the northwest quarter of section 5, Marion township, the terrace is thirty feet above the creek, and a well on the terrace goes forty-five feet into sand, or fifteen feet below the stream level, without reaching the bottom of the sand.

A pit in the northeast quarter of section 4, Marion township, operated by C. H. Grimes, gave the following section:

		Feet.
4.	Leached loesslike clay	3
3.	Unleached loesslike clay with a few bands of pebbles in the basal part	3
2.	Gravel	3
1.	Sand and gravel, above water level	6

The pit is worked by a suction-dredge to a depth of about twenty feet below water level. The material is sand and fine gravel with some cobbles. Several vertebræ and other bone fragments have been pumped up with the gravel.

In the lower course of Deep creek valley just northeast of Le Mars there are two pits from which gravel has been dredged beneath water level. One is located in the northeast quarter of section 10, and the other a mile farther west in the northeast quarter of section 9. The pit in section 10, now abandoned, showed the following exposure above water level:

		Feet.
4.	Soil, passing downward into yellow sandy clay	6
3.	Alternating layers of fine sand and clayey sand, horizontally bedded and laminated	4
2.	Brownish loesslike clay with thin partings of sand. What are apparently rootlet impressions penetrate this clay and iron-staining has taken place along these openings	6
1.	Fresh fine-grained gravel with a few bowlderets 4 to 8 inches through; above water level	10

This pit can be worked to a depth of forty-seven feet below water level, where a layer is struck that is said to consist of flat, slabby pebbles, too hard to be penetrated by the dredge scoop. The material from this pit is fine sand with very little gravel. Details of stratification are of course unknown. At a depth of twenty-five feet a silty layer with stems and vegetable material is passed through. This was penetrated over the entire pit area, which is fifty to sixty yards across.

Tbe pit in the northeast quarter of section 9 shows the following section above water level:

		FEET.
4.	Sandy dark soil	3
3.	Sandy dark gray clay, leached	4
2.	Unleached loesslike clay, containing thin layers of fine sand This is the usual material overlying the gravels but is here thicker and more sandy than common.	15
1.	Fine gravel and sand, above water level	5

Gravel is dredged from this pit to a depth of thirty feet below water level. At this depth a layer of slabby pebbles is struck as in the other pit. Prospect drill-holes have been sunk near by, one of which penetrated fifty-eight feet of gravel below water level. As in the pit farther east, there is, at a depth of twenty to twenty-five feet, a dark silty layer containing vegetable material.

A number of bones have been dredged up from these pits, but no evidence could be obtained as to the horizon from which they came (page 409). They are not greatly altered and have a more modern appearance than bones from the Aftonian deposits of western Iowa farther south.

Deep creek is entirely in the Kansan drift and the explanation of its deep gravel deposit is a rather difficult problem. The valley in which the gravel lies apparently goes through the glacial drift, at least in part, for an exposure of Cretaceous rock exists near the level of Deep creek in the southwest part of section 2, less than half a mile up the valley from the abandoned pit in section 10, where the gravel was worked to a depth of more than forty feet below the creek level. Does this deep valley continue down Floyd river to the Missouri? When was the valley eroded, and when was it filled with gravel? Much more evidence concerning these gravel deposits is required before a satisfactory explanation can be given. Six analyses of pebbles from the gravel deposit of Deep creek valley show an average content of 48 per cent igneous rocks, which is about 12 per cent higher than the average for all analyses made of the valley gravels.

THE LITTLE SIOUX RIVER DRAINAGE BASIN.

This, the largest of the southwestward flowing streams of western Iowa, drains about 3600 square miles (about half) of the area under discussion. In common with its chief tributary, the Ocheyedan, it heads on the Wisconsin drift-plain, and after leaving it near Milford in Dickinson county, it flows near the Wisconsin drift-margin south to the mouth of Brooke creek in northwestern Buena Vista county. It received the drainage of the Wisconsin ice-front from a point east of Sibley to Storm Lake, a distance of 100 miles, and at the present time drains more than a thousand square miles of the Wisconsin drift-plain.

THE HEADWATERS OF THE LITTLE SIOUX ABOVE SPENCER.

The Little Sioux river system above Spencer consists of the Little Sioux proper, the Ocheyedan with its tributary the Little Ocheyedan, and Stony creek, all of which have their upper courses within the Wisconsin drift-region. Along the upper courses of the Little Sioux there are a number of isolated gravel deposits. West of Montgomery in section 29 of Diamond Lake township, Dickinson county, there is an indistinct terrace on the west slope of the valley twenty feet above the stream, consisting of sand with pebbles scattered through it. The pebbles are better rounded than is common for the valley gravels and quartzite is more abundant. A low gravel bench is found also along the lower course of the West Branch of Little Sioux river, and at the union of the two branches in section 7, Lakeville township. In the south part of Lakeville township, terrace remnants along the Little Sioux are more common, and one which begins in the southwest quarter of section 21, thirty feet above the river, can be traced southward across sections 28 and 33, to the township line, where it is forty feet above the river.

In section 33, Lakeville township, a higher bench stands seventy-five to eighty feet above the river, and continues into northern Okoboji township to the margin of the Wisconsin drift where it has approximately the altitude of the Milford bench (page 276). Thick deposits of gravel underlie this bench in the northeast quarter of section 4, where they are seen to rest on till that apparently is Kansan, and copious springs issue from the base of the gravel.

The Okoboji outlet, which drains the lakes of northcentral Dickinson county, joins the Little Sioux southwest of Milford. This course was the outlet of enormous floods of water during the Wisconsin ice-epoch and great gravel deposits appear along it. The extent of this gravel area is shown in figure 31, page 273. At Milford, which stands on this gravel flat, the deposit is twenty to twenty-five feet thick; in the west part of section 12 there are cuts eight to ten feet deep in gravel; and in the southeast quarter of section 11 the south slope of Okoboji outlet shows a gravel stratum forty-five to fifty feet thick with cemented conglomerate layers near the water level. In the southwest quarter of section 12 and the northwest quarter of section 13 the Chicago, Milwaukee and St. Paul Railway Company has excavated great quantities of this gravel for railway ballast. The thickness of the gravel is ten to twenty feet and it rests on blue clay. The gravel of this bench is coarser and more rusty than is the gravel of most of the deposits that are beyond the reach of the Wisconsin ice drainage. Eight analyses of gravels from the Little Sioux valley between the Wisconsin boundary and Spencer show an average of 41 per cent of igneous rocks, which is about 5 per cent higher than the average igneous content of gravels found in valleys that could not have received drainage from the Wisconsin ice.

This gravel area extends as a terrace down the Little Sioux valley to the county line and south to Spencer. At Milford the terrace is seventy to eighty feet above the river, but it declines to fifty feet at the county line, and to twenty feet at Spencer, as shown in figure 54. In this distance the river falls seventy feet while the terrace drops about 120 feet. The fall of the terrace measured along the center line of the filled belt is six and two-thirds feet per mile, and the fall of the river along this same line would be about four feet per mile.

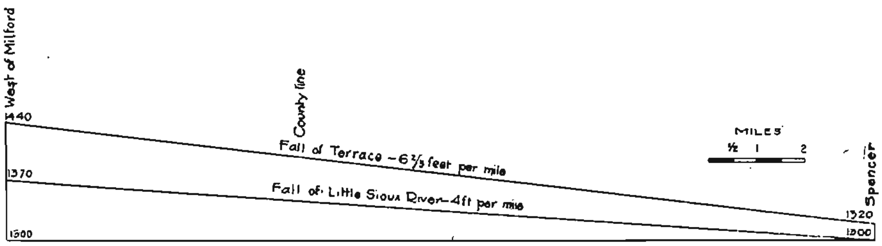


FIG. 54. Profiles along the Little Sioux river valley from west of Milford to Spencer, showing the gradient of the river and the gradient of the terrace. The distance is measured along the central line of the gravel-filled area.

The fall of the river from west of Milford to Spencer, measured along its winding course, is two and two-thirds feet per mile.

In the pits south of Milford the gravel is overlain by two to three feet of brown sandy noncalcareous material with few pebbles. It is not the usual leached loess but bears some resemblance to it and, considering the location of the region, where the loess is almost absent on the upland, this may be the equivalent of the loess. Such an interpretation of the overlying material would make the gravel of the Milford bench pre-Wisconsin, and place it with the valley gravels of the Kansan region. The more rusty character of the gravel, the location of the deposit with respect to the Wisconsin drift-boundary, and the decline of the bench southward to stream level at Spencer seem to separate this gravel deposit from the usual valley gravels and it is most probably Wisconsin outwash.

The upper twenty-five to thirty miles of Ocheyedan river is within the Wisconsin drift-area, and in this part the valley contains very little gravel. South of the Wisconsin drift-boundary in Harrison township of Osceola county and southeast to Spencer, Ocheyedan river has a broad flat, underlain with gravel, but its altitude is little if any above the flood plain.

Stony creek heads within the Wisconsin drift in western Dickinson county. South of the boundary it has a flat one-half to one mile in width, much of which is a low terrace ten to fifteen feet above the creek. Farther south in northwestern Clay county the terrace is absent and the flat is less prominent, although the valley remains broad and open south to its union with the Ocheyedan.

The valley flats of the Ocheyedan, Stony creek and the Little Sioux all unite in Riverton township west of Spencer in a large gravel area (Spencer flat) which extends from Everly eastward through Spencer to the southward bend of the Little Sioux southwest of Dickens. It covers the north half of Riverton township, a strip about two miles wide across Sioux township, and continues west and north up the Ocheyedan and Little Sioux valleys. Probably more than half of this area is a terrace fifteen to twenty feet above the river. Gravel exposures appear at many places. At the pit of the Spencer Cement Tile Company, the gravel is worked to a depth of about twenty feet by a suction-dredge which pumps the gravel from beneath ground-water level. About ten feet of material is exposed above water level, and this consists of cross-bedded fine gravel and sand. Blue clay is said to underlie the gravel and bowlders have been encountered toward the base of the gravel. The gravel is overlain by a brown sandy material similar to that over the gravel at Milford.

TRIBUTARIES OF THE LITTLE SIOUX FROM THE EAST BETWEEN SPENCER AND BROOKE CREEK.

East of Spencer the Little Sioux is joined by Meadow brook, which with its several branches drains those parts of northeastern Clay and southeastern Dickinson counties which lie within the Wisconsin drift-boundary. Small gravel deposits are present along this creek at many places, but not in quantities sufficient to form terraces. Five miles east of Spencer the Little Sioux is joined by the outlet of Lost Island lake (Dickens outlet), and there are considerable gravel deposits along this valley south and southeast of Dickens (Plate XVI, page 268).

Through eastern Clay county and northern Buena Vista county west as far as Linn Grove, the Wisconsin drift-margin lies along or near the east bluff of Little Sioux river and no tributaries of importance enter from the east in this distance. Elk creek, entering at Gillett Grove in southeastern Clay county, has very little gravel along its course, although it drained about six miles of the Wisconsin ice-margin and now drains probably a township of Wisconsin drift-plain. Brooke creek, which flows north along the Wisconsin drift-margin to the Little Sioux, drained eighteen miles of the Wisconsin ice-margin. It has little gravel in its upper course, in Washington and Elk townships, but in its lower course, in Brooke township, there are thick gravel deposits into which the creek and its tributaries have cut deep, narrow valleys.

THE GRAVELS OF THE LITTLE SIOUX VALLEY FROM SPENCER TO ITS MOUTH.

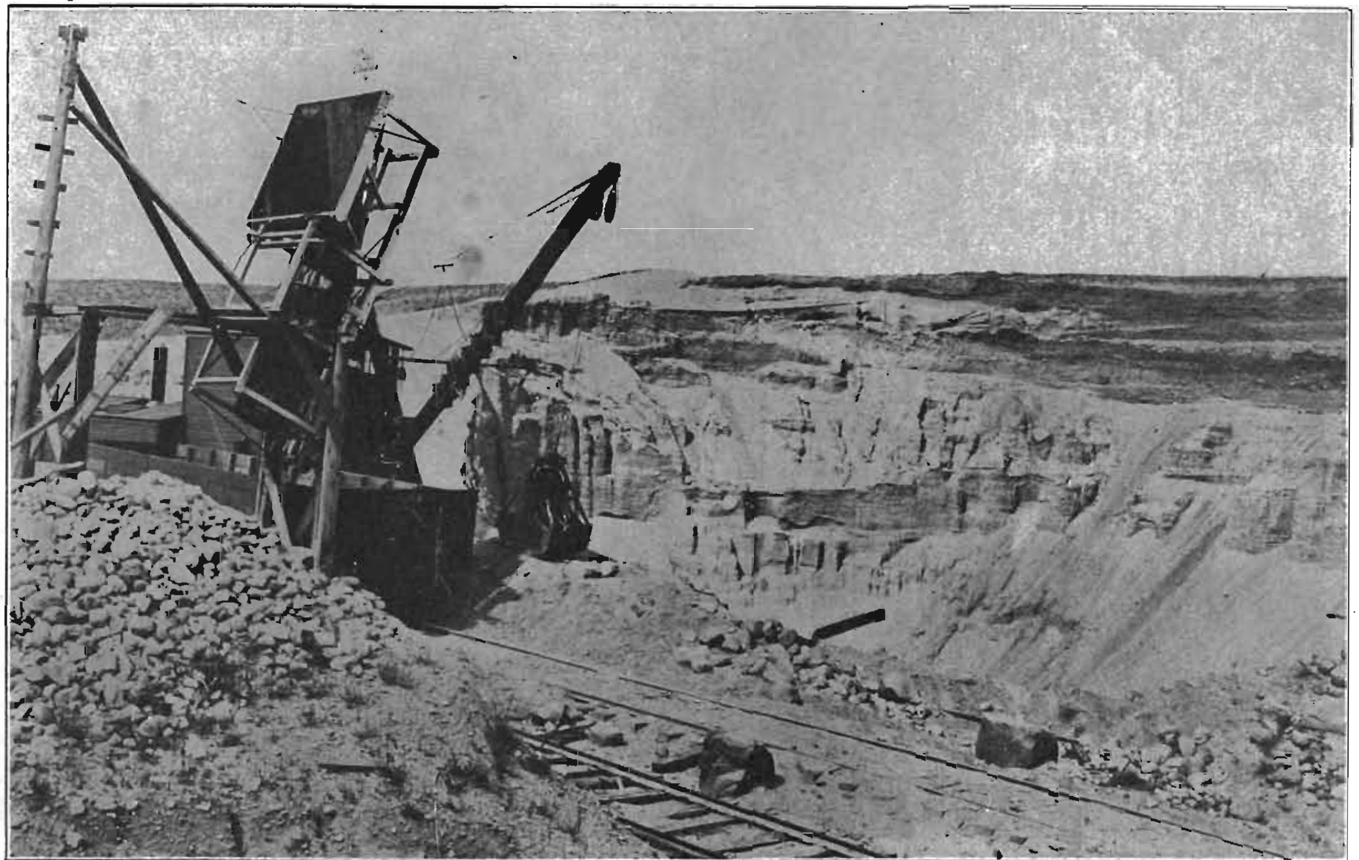
From the bend east of Spencer south to Gillett Grove Little Sioux river flows through a narrow valley and there are practically no gravel deposits. Below Gillett Grove, in Herdland township, there are some small gravel terraces, chiefly along the east slope of the valley, which here marks the Wisconsin drift-margin. At Sioux Rapids the station of the Minneapolis and St. Louis Railway is on a bench about fifty feet above the river and a gravel pit just north of the railway station shows twenty feet of gravel. To the west there are benches at several places, usually on the inner side of the great bends of the valley. There are in places one, in places two, and in places three benches, and their altitudes above the river differ greatly. One common elevation is forty-five to sixty feet above the river.

At the bend of the Little Sioux in southeastern O'Brien county, at the mouth of Waterman creek, there are gravel benches about one hundred and fifteen feet above the river, and only fifteen to twenty-five feet below the adjoining upland. A gravel deposit at this level on the west line of section 23, Waterman township, has a thickness of thirty feet. This terrace continues up Waterman creek valley and up Murry creek valley to Sutherland.

South of the bend and in Cherokee county two bench levels are common; one near the upland, 100 to 120 feet above the river, and another fifty to fifty-five feet above the river (figure 55). In Spring township the higher terrace is found on the north line of section 2; in the southeast quarter of section 17; in the west half of section 29; and at the lower ends of the valleys which enter in sections 16 and 19. The lower terrace is found in sections 3, 2, 9, 16 and 29, and as a large area in sections 17, 20 and 30. At many places this terrace grades down to the flood plain.

In Cherokee township the higher terrace is found in section 13, along the lower course of Mill creek, and southward to and through Cherokee. Lower terraces of considerable area are found north and south of Cherokee, and the town of Cherokee stands on such an area. There seems to be very little uniformity in the altitude of these benches.

In section 14 there are two pits in the terrace, which is here about seventy-five feet above the river, that go down into the deposit fifty and sixty feet respectively. The material is sand and gravel, with a few bowlders. Clay-balls are abundant locally. The material is relatively fresh, but releases an irony dust when it is displaced. The pit of the Cherokee Sand and Gravel Company is sixty feet deep, and the bottom is on a bowlder zone which is said



Gilleas pit in section 14, Cherokee township, Cherokee county. This is one of the largest exposures known in the region. The pit is worked by a steam clam-dipper to a depth of sixty feet below the terrace level. (Beyer, Iowa Geological Survey, volume XXIV, p. 157.)

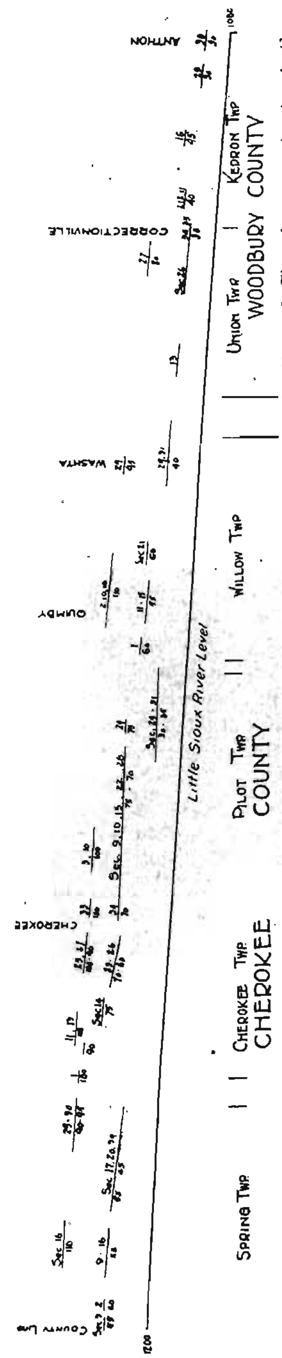


FIG. 55. Sketch showing altitude of benches along the Little Sioux river valley from the north line of Cherokee county to Anthon in Woodbury county.

to rest on 'blue clay". About eighty rods south of this pit is the Gilleas pit which shows a face fifty to sixty feet high, made up of layers of coarse and fine gravel and sand. A view of the Gilleas pit is shown in Plate XXIV. There are many cobbles and bowlderets in this pit, and some very large bowlders. On the basis of the evidence given elsewhere (page 378) the gravel of these pits is not included with the valley gravels but is believed to have accumulated during the Kansan ice-epoch.

Just south of Cherokee the Illinois Central Railway Company has removed the gravel from an area of several acres. An exposure in the east end of this pit showed Kansan till below about twenty feet of gravel.

In Pilot township the most continuous terrace is seventy to seventy-five feet above the river, but other altitudes are represented. At Washta the lower terrace is not over forty feet above the river, and the upper one is ninety-five feet above water level (figure 55). At Correctionville the terraces are still lower, being thirty and eighty feet above the river. Correctionville stands on the lower terrace and the higher one is represented by benches at the mouth of and within the valley of Pierson creek.

The lower terrace is found in Kedron township south of Correctionville, where there is a pit on the west line of section 15; at Anthon where it is thirty feet above the river; and in sections 17 and 18 of Miller township, three miles south of Anthon. Farther south terraces were not recognized, and practically all of the flat is flood plain, at an elevation of twenty to twenty-five feet above the river.

The upper bench level was not positively identified south of Correctionville, but masses of gravel were seen at several places high up on the slopes of the valley. In the southwest quarter of section 20, Miller township, there is some altered gravel eighty-five feet above the river; opposite Oto in section 5 there is a gravel deposit about a hundred feet above the river; and in section 8 there is an exposure of sand eighty to ninety feet above the river. These materials are all altered and do not look like the deposits found north of Correctionville.

Since Little Sioux river drains so large an area of Wisconsin drift, it should have carried much Wisconsin drainage and much gravel along its valley should be of corresponding age. If the course westward across the great watershed is a Wisconsin glacial diversion, then the gravel benches in this part of the valley must be of Wisconsin age. The high bench beginning in southeastern O'Brien county and continuing southward is continuous with benches in valleys that did not receive Wisconsin gravels. Also the gravel of this high bench is overlain by loess in the north part of Cherokee (page 351), in the southwest part of section 31, Pilot township, and at a few other places along the Little Sioux valley and at many places along the courses of the tributary valleys. This upper terrace is therefore preloess in age. The lower terraces are not so definite as to loess covering but the gravel of these, except in the narrow part cut during the Wisconsin time, may also be of pre-Wisconsin age.

MAIN TRIBUTARIES OF THE LITTLE SIOUX FROM THE WEST BELOW SPENCER.

None of the tributary valleys of the Little Sioux from the west, south of the Ocheyedan, which enters at Spencer, received drainage from the Wisconsin ice, and yet these valleys in Clay, O'Brien and Cherokee counties contain prominent gravel deposits, which continue in some cases to the heads of small valleys, whether they head northward, or to the east or west toward some of the interstream divides.

Willow Creek.—The first creek of importance which joins the Little Sioux from the west, south of Spencer, is Willow creek. Along its lower course in section 7, Herdland township, there is a fresh gravel deposit covering a large area and forming benches about thirty feet above the creek and thirty-five to forty feet above Little Sioux river. An analysis of pebbles showed the presence of 72 per cent of sedimentary rocks, all of which were limestone. These gravels are too far from the mouth of the valley to have washed back from the Little Sioux, and therefore are not of Wisconsin age.

Waterman and Murry Creeks.—In its upper course the valley of Waterman creek, which drains eastern O'Brien county, is a broad sag fifteen to twenty feet below the general level, but it deepens within a short distance, so that in its lower course it is more than 100 feet below the upland. In western Omega township there is a gravel bench fifteen to twenty feet above the valley bottom, and gravel extends down to water level. The altitude of this bench above the stream increases very much to the south so that in central Grant township it is seventy feet, and near the mouth of Waterman creek, more than a hundred feet above the stream. Here it unites with the high-level bench of the Little Sioux valley. The relation of the slope of the terrace and the gradient of the creek is shown in figure 56. In Grant and Waterman townships the terraces have considerable area and the gravel in most of them is twenty to thirty feet thick. Waterman creek and its tributaries have cut narrow, steep-sided valleys in the gravel-covered area, leaving level-topped spurs extending out toward the creek from either side and making a very rugged topography. The gravel material is very uniform, consisting of fine gravel with pebbles and small bowlderets. The sand is coarse or medium-grained, sub-angular and the larger grains are dominantly limestone and the smaller grains dominantly quartz.

Murry creek is a tributary of Waterman creek. It heads on the east slope of the high divide of O'Brien county, a mile north of Sutherland and flows south of east to Waterman creek. Its entire length is only eight to nine miles.

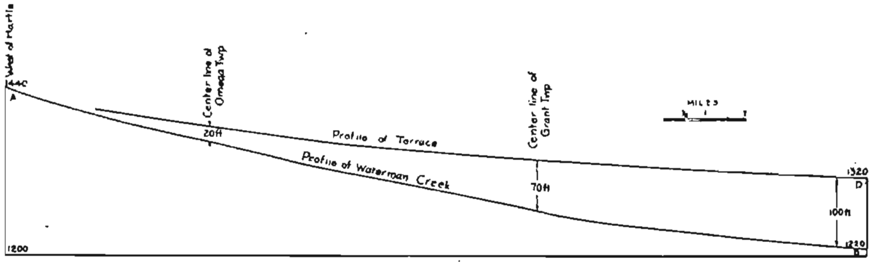


FIG. 56. Profiles along Waterman creek valley from west of Hartley to its mouth, showing, A—B, the gradient of the stream, and, C—D, the gradient of the terrace.

Along its upper course at Sutherland there are several gravel pits exposing ten to fifteen feet of fresh gravel which rests on glacial till and is overlain by two to three feet of loesslike clay (leached loess). At Sutherland the gravel terrace is only fifteen feet above the stream but to the east its altitude is greater as the stream descends, until at the mouth of the creek the terrace merges with the high-level benches of the Waterman and Little Sioux valleys at 110 feet above the valley bed. The terrace in this distance drops 100 feet while the stream drops 200 feet. The slope of the terrace and the gradient of the stream are shown in figure 57.

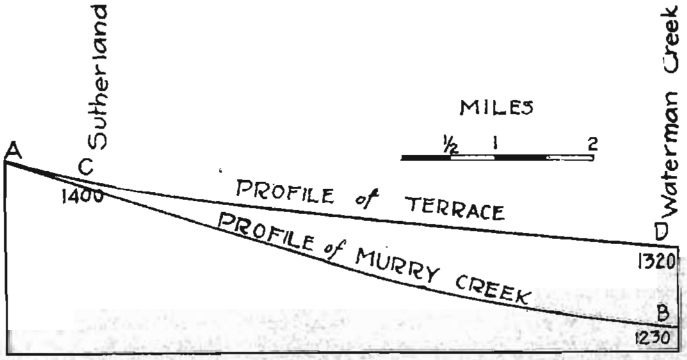


FIG. 57. Profiles along Murry creek valley from Sutherland to its mouth, showing, A—B, the gradient of the creek, and, C—D, the gradient of the terrace.

This valley furnishes one of the best examples of the way the gravels exist in small valleys well out on the upland only a mile or so from the head of the stream. It furnishes very positive evidence against the hypothesis of overwash from the Wisconsin ice-margin to the north. The stream heads on a north-south divide and numerous streams flowing to the east and west drain the divide farther north. If water could have passed over the high divide south of Ocheyedan river, it would have been carried away either to the east or west by some one of a dozen valleys to the north of Sutherland. The altitude of the gravels at Sutherland is 1415 to 1420 feet above sea level. They are on the slopes of the highest watershed of northwestern Iowa.

Mill Creek.—Mill creek, with its tributaries, drains central and southern O'Brien county and central northern Cherokee county. The territory which it drains in its upper part is quite level but farther south its basin is more rolling, so that in northern Cherokee county it is rather rugged. Mill creek did not receive drainage from the Wisconsin ice, for its headwaters are all south of the high divide of southern Osceola county and their gathering grounds are limited on the north by the headwaters of Floyd river and Waterman creek. However, the valleys of Mill creek and its tributaries contain gravel, which in many cases extends nearly to their heads on the upland. This applies to creeks heading east and west on the inter-valley divides as well as to those heading northward.

Three miles west of Primghar several branches of Mill creek unite, and at their union there is an almost level area covering several square miles which appears to be underlain with gravel. The area is not absolutely flat but rises gradually away from the creek and its boundary is in some places quite indefinite. It has an altitude of about fifteen feet above the creek but is not a definite terrace. Projections of this area extend up stream courses to the northwest, north and northeast, and it continues south beyond the center of Dale township. Wells near the quarter-corners on the south of section 33, and the east of section 32 are sunk twenty feet in sand and gravel and one at the quarter-corner on the south of 29 is said to be forty feet deep and all in gravel.

An east branch of Mill creek heads about two miles northeast of Primghar and flows southwest through northwestern Highland and eastern Dale townships. In sections 6 and 7 of Highland township, only a few miles from its head, this valley contains a gravel deposit with distinct benches fifteen feet above the creek. Two gravel pits in these benches show seven to eight feet of fine gravel and sand, overlain by two to four feet of leached loesslike clay. The stream has cut through the gravel, exposing the till beneath. Benches are found farther down the valley through Dale township, as in the southwest corner of section 13, and at the northwest corner of section 26.

At Paullina in Union township the benches lie twenty to twenty-five feet above Mill creek, and there are numerous exposures of gravel along the main valley and in the lower courses of tributaries.

In section 28, Union township, there is a large exposure in a bench forty to forty-five feet above the stream. In part of the exposure the gravel apparently extends to the water level, but elsewhere it rests on greatly altered Kansan till at about ten feet above the stream. The material here is fresh fine gravel with much sand, and is overlain by three to four feet of loesslike clay. On the south side of the valley in the west part of section 34 the bench is about fifty feet above the creek (figure 58). The gravel layer consists of thirty-five to forty feet of fresh coarse sand with pebbles and bowlderets scattered over it. It is overlain by four to six feet of loesslike clay and overlies till which rises six feet above the stream.

Willow and Nelson creeks head in Liberty township north of Calumet, flow westward into Union township, turn southward, unite, and join Mill creek just

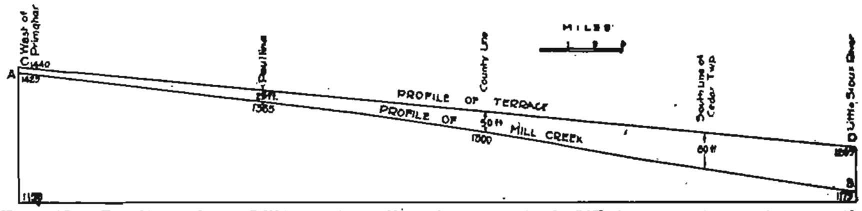


FIG. 58. Profiles along Mill creek valley from central O'Brien county to its mouth showing, A—B, the gradient of the stream, and, C—D, the gradient of the terrace.

beyond the county line. Willow creek has a number of gravel hills along its slopes in Liberty township (pages 365 to 367), but it does not have a prominent valley-gravel deposit. Below the turn to the south in eastern Union township gravel benches are common along these creeks, especially in sections 25, 26 and 36 in southern Union township. On the south line of section 24 a pit shows five feet of very fresh fine gravel, and a well on the bench along Nelson creek in the southwest quarter of section 23 penetrated twenty feet of sand and gravel. A low area connects Nelson creek valley in the west part of section 23 with Mill

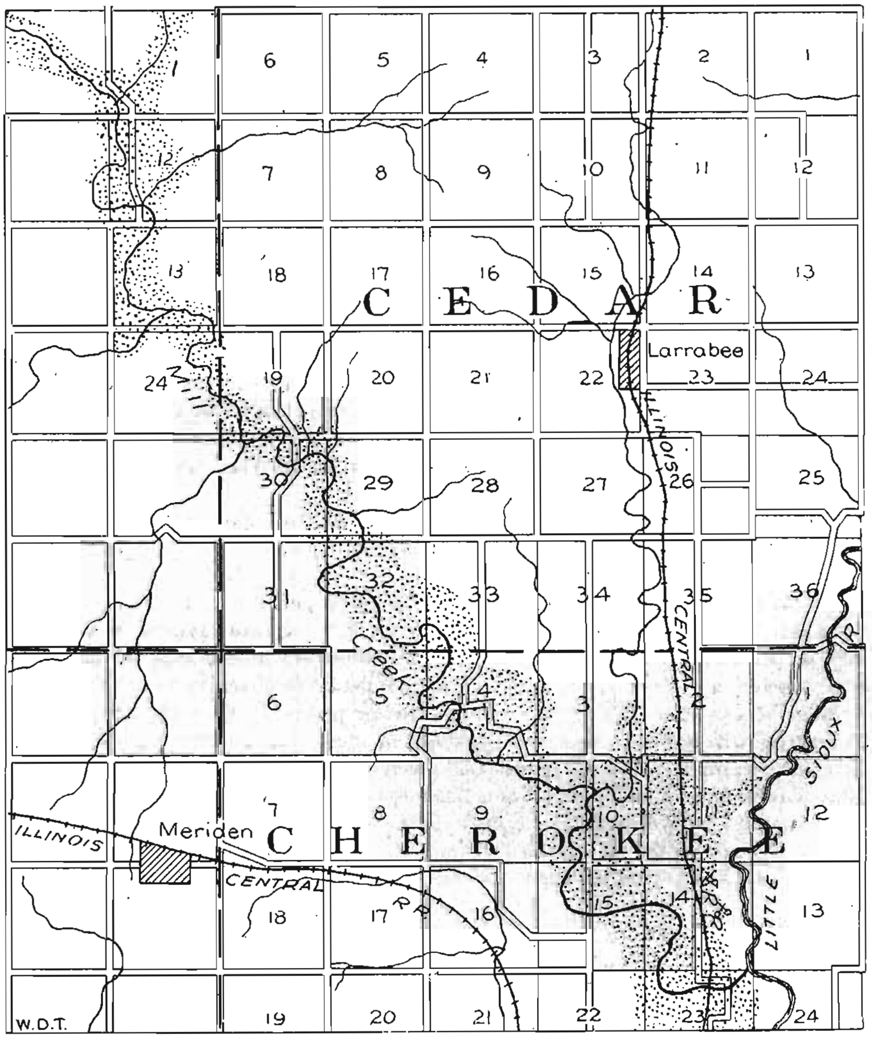


FIG. 59. Map of a part of northern Cherokee county showing by the shaded area, the original extent of the aggraded flat of Mill creek. Part of this area remains as terrace and part has been cut out and now exists as steep slopes or flood plain.

creek valley in the south part of section 15. It suggests an old water course, but the surface is undulating and does not appear to be underlain with gravel.

Farther south in Cherokee county the quantity of gravel material along Mill creek is larger although the benches have small areal extent and are by no means continuous. The original width of the aggraded flat, as shown in figure 59, was about a mile, but much of this area has been cut out and is now in steep slopes or narrow flood plain. The altitude of the benches above the creek is greater to the south, as is shown in figure 58, so that on the south line of Cedar township they are seventy-five to eighty feet above the creek and near the mouth of the valley they stand almost a hundred feet above the stream. The benches occupy alternate positions on the valley sides where the stream swings back and forth, and some of them are half a mile wide.

The Mill creek bench extends into the lower course of a tributary valley in the northeast quarter of section 10 and the east half of section 3, Cherokee township, and from this valley a prong of the bench extends southeast across the northwest quarter of section 11 to the Little Sioux bench (figure 59). At the time of maximum aggradation this prong separated an area of upland in the southwest part of section 11 and the northwest part of section 14 from the upland to the north.

MINOR TRIBUTARIES OF THE LITTLE SIOUX IN CHEROKEE AND WOODBURY COUNTIES.

Through Cherokee and Woodbury counties there are many small valleys, tributary to the Little Sioux, that have gravel in their lower courses. In general the benches of these valleys are continuous with those of the Little Sioux valley. In some cases the gravel may have been carried into the tributary valleys from the main valley, but in most cases it continues too far up the tributary valleys to have been derived in this way.

In section 11, Spring township, in the northeast corner of Cherokee county, a small creek enters the Little Sioux from the east, and in the northwest quarter of section 12, there are benches along this valley 105 to 110 feet above the creek. The material exposed is relatively fresh sand with pebbles, and seems to have a thickness of ten to twenty feet, and rests on till. A thin layer of gravel was seen on the slope of this valley near its head two miles farther east in the northeast quarter of section 7, Brooke township, Buena Vista county.

Most of the east half of section 16, Spring township, is a terrace 110 feet above the Little Sioux, and a projection of this extends east up this valley through section 15. The creek flowing southward through sections 19 and 18 of Spring township is bordered by benches sixty-five feet above the creek, and the gravel, which is twenty to thirty feet thick, rests on till. Gravel benches exist also along the valley in sections 24 and 25, Cedar township, especially in its lower part, where they become continuous with the bench of the Little Sioux valley.

In Cherokee township, there are gravel deposits in tributary valleys in sections 1 and 13, in the valley from the northwest at Cherokee as far up as the central part of section 21, and in the valley which enters from the northwest just south of Cherokee. The higher bench of the Little Sioux valley continues into both of these tributary valleys near Cherokee.

In Pilot township two small creek valleys from the east contain notable gravel and silt deposits. One of these is in sections 10 and 11 and the other in the north parts of sections 22 and 23. The higher terrace of the Little Sioux valley continues into the lower end of the valley in section 10 and is represented in this valley by gravel benches which extend almost to the township corner. Similar benches are present also in secondary branches from the southeast. In most of the exposures the material is clean fine gravel and quartz sand, as in the railway cut in the northeast quarter of section 11, and above a prominent spring zone on the south side of the valley near the west line of section 11. The valley contains also at some places deposits of silty sand and iron-stained silty material. In the lower part of the valley where the creek crosses the terrace of the Little Sioux, and at a number of places farther up the valley the gravel and silt deposit rests on Nebraskan till, but elsewhere and especially in the upper course of the valley it rests on Kansan till.

The higher bench of the Little Sioux valley also extends into the mouth of the tributary valley in the north part of section 22 and is marked by small benches on the valley sides eastward beyond the central line of section 23. At the mouth of the valley the terrace is eighty feet above the creek, but the gradient of the creek bed is so great that a mile east the benches are only fifteen feet above the stream. In this distance the terrace rises twenty-five feet but the creek rises ninety feet. Where the valley crosses the quarter-section line of section 23 the gravel rests on Kansan till, which in turn rests on Nebraskan till, but farther down the valley the Kansan till is absent and the valley-filling rests on the Nebraskan. The south slope of the valley in the northeast part of section 22 showed the following exposure:

	FEET.
5. Alternating layers of gravel and sand with a few pebbles and bowlders	17
4. Medium-grained sand, with coarser layers toward the top and grading into the silt horizon below	15
3. Alternating thin layers of compact blue silt and sandy silt. Some of the silt layers are fossiliferous	17
2. Coarse sand and fine gravel with a layer of bowlders at the base. Material much iron-stained and locally cemented. Copious springs issue from the base of this member	5
1. Nebraskan till; a very tough greenish blue till with very few pebbles	9

The upper two members of this section appear to be the typical valley gravel. The silt member (No. 3) may be a slack water deposit put down in the tributary valley as the Little Sioux valley was being aggraded. Gravel is exposed in the slopes of this valley farther west, in the terrace of the Little Sioux, where a spring zone, twenty to twenty-five feet above the creek, probably marks the top of the Nebraskan till.

In the lower course of Parry creek, which drains the western part of Pilot township, there are a few benches high up on the slopes about seventy feet above the creek, and about thirty-five feet above the lower terrace in the Little Sioux valley. Benches are found at intervals up the valley. Rock creek, which joins the Little Sioux north of the center of Willow township, also has along its lower course benches which are continuous with high narrow benches along the Little Sioux valley to the north and south. These are present at intervals up the valley to the center of Rock township, and decrease in altitude until they are only fifteen feet above the creek.

Opposite Correctionville in northeastern Woodbury county, the high level bench of the Little Sioux valley, eighty feet above the river, continues into the lower end of Pierson creek valley. A gravel pit in this bench at the northwest corner of section 34, Union township, at the mouth of the valley, showed twenty-three feet of fine-grained gravel and sand. The Walsh Brothers' pit near the center of the southeast quarter of section 28, half a mile within the valley, showed twenty-five feet of gravel overlain by four feet of fine sand and above this about three feet of leached loess. An abandoned pit at the center of section 20 showed ten feet of gravel over blue Kansan till and overlain by three to five feet of sand and sandy clay. Benches of gravel continue up the west branch of the creek to Pierson and are present in the lower course of the north branch. The material exposed in these pits is almost entirely clean quartz sand and fine gravel, and is more worn than are the valley gravels farther north. Four analyses of pebbles from this valley show an average of 47 per cent igneous rocks, which is 11 per cent higher than the content of average valley gravels, and the sand averages about 95 per cent quartz grains. There are small snail shells in the gravel, and the pits in sections 34 and 28 have yielded some vertebrate remains (page 409).

The material overlying the gravel of the benches in the lower course of Pierson creek valley is not usually distinctive loess but leached loess overlies the gravel at the Walsh pit and the sand and sandy clay of other exposures is undoubtedly the time equivalent of the loess. The stratigraphical position of the gravel below the loess is well shown on the north line of section 20 where a gully on the west slope of the north branch of the creek shows seven feet of loess, the upper three feet of which is leached, overlying twenty feet of gravel. The continuity of this gravel with that farther down the valley cannot be questioned, as this exposure is only half a mile from the pit exposure of section 20.

MAPLE RIVER DRAINAGE BASIN.

Maple river heads in northwestern Buena Vista county and flows southward through eastern Cherokee and Ida counties to Ida Grove. Here it changes direction to southwest and holds this course to its union with the Little Sioux southeast of Onawa. In eastern Cherokee county this river has a broad upland valley with a large flat, much of which is overflowed by the river at times of high water. In northeastern Ida county the valley is deeper where it enters the more rugged part of the Kansan drift-region and from here southward it is a broad, open valley more than 100 feet deep.

The basin of Maple river is separated from the Wisconsin drift-margin by the high north-south divide of western Buena Vista and Sac counties and by the Boyer river valley. No Wisconsin drainage could possibly have entered the valley.

The broad valley of Maple river through eastern Cherokee county is probably underlain with gravel material, but the river has only a shallow channel and gravel was seen at only a few places. In Galva township of northeastern Ida county, gravel was seen in benches at the northwest corner of section 10 and in sections 22, 27 and 34. The valley joining Maple river valley at Galva is bordered by gravel benches through the north part of section 23, and a pit just north of Galva shows ten feet of clean gravel and sand overlain by five feet of yellow loesslike clay which probably is leached loess.

At Ida Grove, Maple river is joined by Odebolt creek from the east. On the south side of the latter, in the west part of section 19, Blain township, there is an exposure of about fifteen feet of sand with a few pebbles, and there is an abandoned gravel pit just northeast of the railway station at Ida Grove.

BOYER RIVER DRAINAGE BASIN.

Boyer river heads southwest of Storm lake in southern Buena Vista county and flows east of south to southern Sac county. In this portion of its course it is four to six miles west of the Wisconsin drift-margin and received drainage from the Wisconsin ice by a break through the divide to the east just north of the Buena Vista-Sac county line and by the Wall lake outlet south of the town of Wall Lake. From southern Sac county, Boyer river flows southwest across Crawford and Harrison counties to Missouri river.

The headwaters of the Boyer river above Early occupy broad, upland valleys. Flat areas, that apparently are underlain with gravel, are found along the valleys of Eden township, but the streams have cut only shallow channels into them and exposures are few. In Boyer Valley and Clinton townships the valley is deeper. Gravel deposits were seen at a few places.

The Wall lake outlet connects the Boyer valley with the Wisconsin plain and with a great gravel deposit of Wisconsin age at the west end of Wall lake. The bottom of the outlet is a swampy flat, projections of which extend up small tributaries of the Boyer into northwest Levey township.

Southwest of the Wall lake outlet, across Crawford county, the Boyer valley **has steep slopes and** a flat bottom which is at flood plain level, and is in most places one-half to one mile wide. At a few places, especially at the mouths of tributary valleys, there are benches that look like remnants of a former valley filling.

Fossils From the Valley Gravels.

The valley gravels, especially in the southern part of the area, have yielded some fossil remains. These include both vertebrates and mollusks.

The two deep pits just northeast of LeMars (pages 394 to 395) have yielded a number of bones. They were brought up by the dredge scoop and are said to come from different depths. Among the material from these pits are elephant tusks and teeth, part of a pelvic girdle of an elephant, deer horns, horse teeth and a number of unidentified leg bones and vertebrae. Remains, chiefly deer horns, limb bones and vertebræ have been obtained also from the Erdman pit in the Floyd river valley in the northwest part of LeMars (page 393) and from the pit operated by C. H. Grimes in Deep creek valley one mile east of Oyens (page 394).

From the pit of the Cherokee Sand and Gravel Company north of Cherokee a tooth of *Elephas columbi,* an elephant tusk, and various small bone fragments have been taken.

Two specimens obtained from the pit of the Walsh Brothers in Pierson creek valley west of Correctionville were identified by Dr. O. P. Hay[55] as "a horn core and the base of a skull of a bison, both belonging to *Bison occidentalis.*" The writer examined a large proboscidian tooth, a horn core, a horse tooth, and some pieces of unidentified bones which were taken from the gravel pit of Paul Fleming, at the mouth of Pierson creek valley. A few miles south of Correctionville, within the Little Sioux valley, is the Gilleas gravel pit, from which a "buffalo head", deer horns, a worn tooth of *Elephas primigenius* and various bone fragments have been taken.

Some proboscidian bones have been found in the gravel deposit of Rock river at Rock Rapids. This locality is well out in the Kansan drift area, but the valley may contain Wisconsin gravel.

The bones found in the gravels of northwestern Iowa are, so far as known, all isolated finds and many of the bones are worn. No complete skeletons have been found. The evidence is not such as to prove that the animals lived while the gravel was accumulating, although this was probably true.

Small snail shells were found in the gravel at several places in the southern part of the area, mostly in the tributary valleys of the Little Sioux at or near their union with the main valley. They were found in coarse sand and fine gravel as well as in silty sand and silt deposits.

In the creek valley in the northeast quarter of section 11, Pilot township, Cherokee county, gastropod shells were found in fresh coarse sand in a railway cut. In the next creek valley to the south in the northeast quarter of section 22 (page 407), small gastropod shells were found in a compact silt that forms part of the valley filling.

The gravel in the Paul Fleming pit at the mouth of Pierson creek, opposite Correctionville, contains many snail shells. At least five species were collected here, although most of the shells belonged to one species.

South of our area, in Crawford county, shell-bearing gravels were found in two tributary valleys of the Boyer. Along

[55]Iowa Geol. Survey, Vol. XXIII, p. 74.

Porter creek in Stockholm township, north of the village of Boyer, there is a gravel deposit which forms benches thirty to forty feet above the creek, and snail shells were found at several places in the fresh sand and fine gravel in these benches. At the lower end of the valley just southwest of Boyer, mussel shells (unios) were found in a brownish yellow to blue-gray silt zone. Farther south in the southwest part of section 6, Washington township, just above the mouth of the valley of Buck creek, which joins the Boyer near Arion, there is a bed of fresh, clean gravel which contains many gastropod shells. The zone is part of a thirty foot bank of sand and gravel which is overlain by fossiliferous loess.

All the gravels containing molluscan fossils and practically all those containing vertebrates are located in the southwest part of our area. None of the gravels of the northern part of our area are fossiliferous. The deposits along Mill creek and elsewhere were examined carefully for fossils, but none were found.

Origin and Age of the Valley Gravels.

The term valley gravels is intended particularly for those gravels which occupy valleys in the Kansan area that could not have been reached by outwash from the Wisconsin ice-sheet, and which are, therefore, not Wisconsin gravels. However, in the above discussion of the distribution of the gravels, all gravels occupying valleys have been treated, because in most cases it was not possible to differentiate those occupying valleys that did not receive Wisconsin drainage from those in valleys that did receive such drainage. In treating the origin we are concerned with only the true valley gravels.

The valley gravels rest on the Kansan till, except where the Kansan till had been entirely removed at the time of gravel deposition, as in the Little Sioux valley and the lower courses of some of its tributaries, in which case they rest on the Nebraskan till. The gravels are in valleys cut into or through the Kansan drift-sheet. They are therefore post-Kansan in age and must have been deposited only after sufficient time had elapsed to permit the previous development of the valleys to essentially their present depth and form. Furthermore it is believed (page 332) that the Kansan drift-plain remained for a great length of time in such a position that it was not being eroded, and that the gumbotil was developed on this plain. The region was then uplifted, and erosion had reduced the entire surface below the gumbotil plain before the deposition of the gravel took place. The gravel may, therefore, be much younger than the Kansan epoch.

The gravels are generally overlain by a pebbleless, loesslike clay which is continuous with a similar deposit over the upland. In the west and southwest parts of the area studied this deposit over the upland is the undoubted loess; and over the remainder of the Kansan drift of our region this deposit, although thinner and in most places leached for its entire thickness, is the time equivalent of the loess (page 343). The material overlying the valley gravel is, therefore, the time equivalent of the loess although it is not for the most part true loess in the lithological sense. The loesslike clay apparently was deposited soon after the gravels, for the top of the gravel deposit does not show the least indication of a weathered zone. In fact it appears that there was a transition from gravel deposition to deposition of loesslike clay, for there is at many places alternation of the two materials near the contact and a recurrence of sand and pebble bands in the lower twelve to eighteen inches of the loesslike clay. The lower part of this loesslike clay shows banding in some exposures and must be water laid. The upper part may be eolian, a method of origin which would accord better with its texture and its general lack of bedding.

The age of the gravel is, therefore, post-Kansan and pre-loess, which probably means pre-Iowan. It was deposited long after the Kansan epoch and probably just preceded the formation of the loess.

Most of these valley gravels of northwestern Iowa were interpreted as Wisconsin gravels by Professor Macbride. At first they were interpreted as being largely within the area of the Wisconsin drift, the boundary of that drift-sheet being placed far enough southwest to include O'Brien county; later, when the Wisconsin drift-boundary was shifted to the Ocheyedan-Little Sioux course (page 254) the gravels of the extra-morainic region were interpreted as being due to waters which broke over the great divide and flooded the country to the southwest. With the margin located across Sac, Buena Vista, Clay, Dickinson and Osceola counties as described in another part of this report (pages 255 to 287) it is possible to determine which streams could have received drainage from the Wisconsin ice. These are Big Sioux river; Rock river and its tributary, Little Rock river, with Otter creek; Little Sioux river and its tributary, Ocheyedan river, with the Little Ocheyedan; and Boyer river. The drainage courses of Floyd river, Mill creek, Waterman creek, Maple river and others which contain valley gravels could not have received Wisconsin drainage. Therefore, from the viewpoint of the possible distribution of Wisconsin outwash, the valley gravels could not all be of Wisconsin age.

In composition the gravel is like that of the clay-ball hills and the inclosed gravel-masses, and closely resembles the pebbles that may be picked from the Kansan till. Clay balls and shale pebbles are not common, as they are in the gravels of the gravel hills, indicating that these gravels were subjected to some transportation; and yet they were not transported far enough to wear out the limestones or to round the pebbles, most of which are subangular.

It is believed that the material that forms the valley gravels was derived from the Kansan till, from which it was released by erosion, and that it collected gradually in the valleys as the finer material was carried beyond the region. The conditions under which gravels would accumulate so widely in the valleys are not well understood. They may be climatic and associated with the decreased vegetation and increased erosion of an ice-epoch, during which, although the ice did not invade this region, its climatic effects were strongly felt. The gravels may represent the declining stage of a period of rapid erosion which had been caused by an uplift of the gumbotil plain.

It is thought that a method of uplift that affected first the northern region and then progressively regions farther south might afford an additional basis in explaining the phenomena. If the northern counties of the state were uplifted it would result in rapid erosion of that district. Later uplift farther south would result in rapid erosion in the newly uplifted part but would also have the effect of slackening erosion farther north and possibly might cause deposition. Uplift affecting regions progressively farther south might ultimately result in gravel deposition along most of the length of the southward flowing valleys. Gravel once deposited might be later shifted farther down the valley, which would result in the material being more and more worn.

It is believed that the method of origin outlined above is similar to the way in which the Aftonian gravels accumulated and that if the Kansan region of northwestern Iowa had been overridden by a later ice-sheet, deposits similar in position to the Aftonian gravels would have been formed.

CHAPTER VI

THE NEBRASKAN DRIFT.

The Nebraskan drift, under the name of pre-Kansan or sub-Aftonian, has been known in Iowa for many years.[56] The term Nebraskan was proposed by Professor Shimek in 1909.[57] In 1908, Professor Shimek discovered a mammalian fauna in the Aftonian gravels of western Iowa. This gave new impetus to the study of these gravels, and the Nebraskan drift below the gravels has since received more attention. The work of Professor Shimek in Harrison and Monona counties and later along the entire western border of Iowa has brought to light many exposures of Aftonian gravel and of the underlying Nebraskan drift between northern Missouri and the northwest corner of Iowa.[58]

GENERAL CHARACTERISTICS.

Within the region here considered the Nebraskan till is exposed chiefly within the valley of Little Sioux river, which in part of its course, chiefly in Cherokee county, has cut through the Kansan till into the Nebraskan. The bottom of the valley is

[56]For bibliography see Iowa Geol. Survey, Vol. XXII, pp. 661-663.
[57]Science, Vol. 31, p. 75, 1910.
[58]Shimek, B., Bull. Geol. Soc. America, Vol. 20, pp. 399-408; Vol. 21, pp. 119-140; Vol. 22, p. 730; Vol. 23, pp. 125-154. Iowa Geol. Survey, Vol. XX, pp. 304-366.

covered with alluvium and glacial gravels so that there are few exposures of the Nebraskan till and its extent at the surface is negligible, although the actual area where it directly underlies the alluvium and gravels may be considerable. The exposures of Nebraskan till are found in the valley bottom or in the lower parts of the bluffs, and at no place do they rise more than half way to the level of the upland. They are found also along the lower courses of some of the tributary streams, especially along Mill creek in northern Cherokee county.

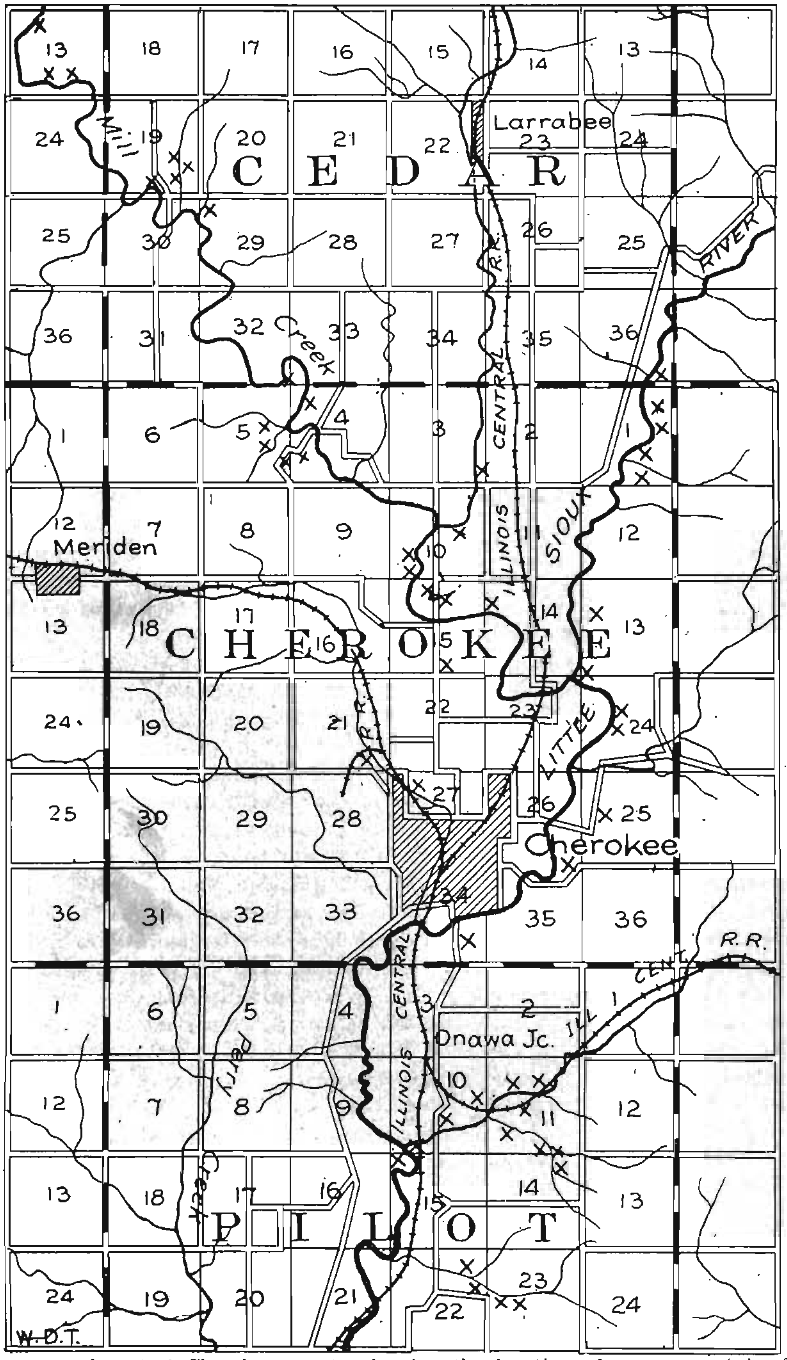
The Nebraskan till of Cherokee county is gray modified by various tints of chocolate, brown, purple and blue. The most common colors are chocolate gray and purplish gray, and generally the color is darker with greater depth beneath the face of the exposure. In its most weathered phase it has a yellowish cast. The till is almost free from pebbles or sand grains, and is so fine-grained that in most cases very little grit can be detected even when a small piece is tested between the teeth. The matrix of the till is commonly calcareous but at some places it is only slightly so or even is entirely free from calcareous material, although it is the fresh unaltered till. Calcareous concretions ranging in size from small grains to masses eight or ten inches across are found in the upper part of this till in some of the exposures. The till is compact and tough when fresh, but in most surface exposures it is loose, and can be dug easily with the hammer. It has a peculiar and characteristic method of fracture by which it breaks up into small angular fragments similar to those into which starch fractures on drying.

The Nebraskan is overlain by the valley gravels, by the Kansan till, or by silts and sandy silts, probably of Aftonian age. Aftonian gravel and sands, which are so general farther southwest, are not found here. The thickness of the Nebraskan till is not definitely known, for no exposure goes through it, and well records are usually too indefinite to distinguish between the Nebraskan and Kansan tills. In several exposures along the Little Sioux it rises fifty to seventy feet above the river, and the record of a well on the upland at the Cherokee State Hospital is interpreted as penetrating 170 feet of Nebraskan drift below seventy feet of Kansan. It is probable that the major portion of the 200 feet or more of Pleistocene material which covers parts of northwestern Iowa is Nebraskan drift.

In this region the Nebraskan till is easily distinguished from the Kansan. Its surface color is gray, while that of the Kansan is brownish yellow, and the fresh till has a darker color than has the Kansan under similar conditions. It is more compact and tougher than the Kansan, and is the abomination of those who dig wells and grade roads. It contains less grit and fewer pebbles and bowlders, and breaks up into much smaller fragments. The two tills are so distinct that in most places where the contact was exposed it was possible to locate the plane exactly, and in several places hand specimens could be taken that contained both tills. In some places the Kansan ice plowed up the Nebraskan till and left a transition zone at the contact.

South of our region in Carroll and Crawford counties and in places farther south the Nebraskan till is practically identical with the Kansan, since it oxidizes to the same yellow-brown color as the Kansan and contains much sand, pebble and bowldery material.[59] Also in this region to the south there is at the top of the Nebraskan a gumbotil which is similar to the gumbotil at the top of the Kansan till.[59a] This Nebraskan gumbotil is distinct from the Nebraskan till of that region, which is yellow when oxidized. The upper part of some of the Nebraskan exposures of our region may represent this gumbotil zone but its separation from the Nebraskan till below is more difficult because the latter is itself a gray, tough, almost pebbleless clay and does not oxidize to a yellow color. The limestone pebbles are gone but these are so rare in the fresh till that one must sometimes shave down half a bushel of the till before finding a pebble. The calcareous material must be leached from the matrix but as noted above the matrix of the fresh till is at some places without calcareous material. Furthermore, in the Nebraskan gumbotil there are calcareous concretions, which have been formed by the material carried down from the overlying Kansan till, and these may be small grains which are hardly recognizable until tested with acid. The work in northwestern Iowa was done before the Nebraskan gumbotil had been recognized in southern Iowa, and later work may differentiate it in this region.

[59]Kay, G. F., Iowa Geol. Surv., Vol. XXVI, p. 231.
[59a]Kay, G. F., Science, Vol. 44, p. 637; Iowa Geol. Surv., Vol. XXVI, pp. 217 and 231.



A map of central Cherokee county showing the location of exposures (x) of Nebraskan till.

DISTRIBUTION AND DESCRIPTION OF OUTCROPS.

There are many exposures of Nebraskan till in central Cherokee county and a number of these will be described here. The locations of the more important of these exposures are shown on Plate XXV.

In the northwest corner of section 15, Pilot township, at a point where the river changes direction from west to south, the west bank of the channel exposes a hard blue-black clay that apparently is Nebraskan till. It has a starchlike fracture, rises three to four feet above low-water level, has a thin reddish brown band at the top and is overlain by a layer of ferruginous material with many cobbles and bowlders. Above a rise of a few feet in which the material is not exposed, the bench gravel is exposed and rises thirty feet to the terrace level.

The creek valley in sections 22 and 23, Pilot township (pages 406 to 408) has some good Nebraskan till exposures along its lower course (Plate XXV). Just east of the quarter-section line of section 23 a tributary ravine from the south shows twenty feet of Nebraskan till overlain directly by Kansan till. The Nebraskan till here is a gray compact clay which breaks into small angular fragments. It contains very little grit, but few pebbles, and many calcareous concretions. Other exposures of the Nebraskan-Kansan contact are found along the south slope of the creek valley for twenty or thirty rods west of the quarter-section line and none of them show gravel between the tills. In one exposure in a ravine from the south about twenty rods west of the quarter-section line, there is between the tills a purplish gray siltlike clay with bands of dark alluvium, and this is probably reworked Nebraskan material of Aftonian age.

Farther down the valley there are several exposures of Nebraskan till overlain by the valley-filling material without the intervention of Kansan till. Near the center of the northeast quarter of section 22 the Nebraskan till rises about nine feet above the creek in the base of a large slide (No. 1 of section on page 407.) The till here is very tough greenish blue clay with very few pebbles. It is overlain by five feet of much rusted gravel with a layer of bowlders at the contact. The gravel has an indurated ferruginous zone at the top, and irregular cemented masses lie on the slope. Strong springs issue from the base of the gravel zone at the top of the Nebraskan, and springs at similar altitude at other places along the valley probably come from the same horizon. Above this horizon rises fifty feet of bedded valley-filling material that is dominantly silt and fine sand in the lower part and dominantly gravel toward the top. The valley-filling material here rests on the Nebraskan till but it occupies a valley cut into and through the Kansan till and rises to a bench within a post-Kansan valley. It is, therefore, of post-Kansan age and was deposited in a valley which had been cut through the Kansan till and which had its bed, as at present, in the Nebraskan till.

About 100 yards northwest of the large slide exposure the Nebraskan till rises ten feet above the creek. It is here a dark greenish blue clay, which in the upper part is weathered and contains much concretionary calcareous material.

Farther north in Pilot township there are a number of small exposures of Nebraskan till in the lower part of the slopes of the creek valley in sections 10 and 11 (Plate XXV). The Nebraskan till here is blue-gray clay with very few pebbles or grains of sand. It is sticky and gummy when wet and dries with a very hard crust. On slopes that have been exposed for years the till is loose, and breaks out with the starchlike fracture. It contains calcareous material along joints and as concretions.

Within the area of the Little Sioux bench in the central part of section 10, the Nebraskan till is exposed in the road-cuts on both slopes of the creek valley and in a railway cut just south of the creek. In all these exposures the Nebraskan is overlain by the gravel horizon of the terrace. In the road-cut in the north slope of the valley the till is exposed through a vertical range of thirty to forty feet and rises to an altitude of 1240 feet above sea level, or about eighty feet above the Little Sioux. In a railway cut on the east line of section 10 the blue-gray Nebraskan till is exposed, while higher up the valley slope the Kansan till outcrops. Other exposures were seen in the ravine from the north in the northwest quarter of section 11; in the slope on the south of the railway, just west of the quarter-section line of section 11; at the southwest end of a railway cut in the northeast quarter of section 11; and in the creek bank south of the east end of this railway cut. Nebraskan till exposures appear also along the tributary valley from the southeast in the southeast quarter of section 11, and the northeast quarter of section 14.

The Nebraskan till is exposed in the lower part of the terrace front of the Little Sioux valley, along the road leading south from Cherokee. The road-bed here has been sunk a few feet below the natural surface and the till exposed at the road-side is so hard that at a few inches beneath the surface little impression can be made on it with a hand pick. Those who helped cut the road tell in strong terms of the toughness of the clay. A little farther up the slope a ravine bed east of the road shows a more weathered phase which is less hard, is plastic and gummy where wet, and is streaked with calcareous material. The upper contact of the Nebraskan till was not seen here but the till apparently is overlain directly by the gravel layer which forms the upper fifteen to twenty feet of the slope which rises to the level of the terrace.

In two wells about fifty yards west of these roadside exposures and near the top of the slope, a very hard, blue-black clay was struck just below the gravel and one of these wells penetrated this horizon about ninety-five feet without striking any water-bearing material. This depth would place the bottom of the well at an altitude of about 1120 feet above sea level, or forty-five feet below Little Sioux river. About 200 yards west of the road, at the east end of the old Illinois Central Railway gravel pit, the Kansan till underlies the gravel at about the same altitude as the Nebraskan till exposures along the road.

The town of Cherokee stands on a bench about thirty-five feet above the river. Gravel underlies the bench directly but in 1913 several sewer ditches in the northeast part of town exposed Nebraskan till at a depth of three to five feet. A layer of bowlders, some of them two to three feet in diameter, rests on the till.

One mile northwest of Cherokee, in the northwest corner of section 27 (Plate XXV), a railway cut exposed the weathered, loose phase of the Nebraskan till, which was overlain by the valley gravels. A few rods away another cut exposed fifteen feet of Kansan till, also overlain by the valley gravels. These exposures and those just south of Cherokee noted above, show how the gravels may rest on the Nebraskan and the Kansan tills at points close together. Where the railway spur to the State Hospital grounds crosses the creek in the southeast quarter of section 21, the excavations for the bridge piers exposed in 1916 about ten feet of chocolate-gray Nebraskan till, which contained a few pebbles, and also had many irregular calcareous concretions in its upper part.

Nebraskan till is exposed in the lower part of the east slope of the Little Sioux valley along the wagon road leading east from Cherokee (Plate XXV). The exposure extends along the road for more than 100 feet and for most of this distance the cut is ten to twelve feet deep. It covers a vertical distance of thirty-five feet and rises to an elevation of 1250 feet above sea level, or approximately eighty feet above the river. The lower part of the exposure shows blue-gray compact gummy clay that is slightly calcareous and contains a few limestone pebbles. It has the typical starchlike fracture of the Nebraskan and at a depth of six to nine inches below the face of the exposure the clay is very compact and hard. The upper part of the exposure, about fifteen feet, is not the typical Nebraskan till, although it is very similar. This part is more plastic, looks like a massive silt deposit and breaks up into small fragments similar to the starch fracture. This zone contains calcareous matter as powdery material along the joints, and in the form of concretions, whose diameters range from the size of sand grains to two inches, but no limestone pebbles were found and the matrix is thought to be leached. However, it is difficult to determine whether the effervescence produced is by a small concretion, by a small grain of limestone, or by a calcareous matrix of clay. It is believed that this zone is the Nebraskan gumbotil, that it was thoroughly leached before the Kansan epoch and that the calcareous material is all in the form of concretions and has been carried down from the Kansan till above. The upper contact of the Nebraskan till was not exposed, but Kansan till is exposed twenty-five yards farther east and twenty-five feet higher and this continues to the top of the slope.

Fifty yards east of the turn in the road at the base of the bluff in the west part of section 25, Cherokee township, a small gully exposes yellow-brown Kansan till over a black humus-bearing tough clay, which apparently is the top of the Nebraskan. Farther north along the bluff at the same altitude there are several places where water seeps out, and just down the slope is a black gumbo material that is probably derived from the Nebraskan till.

Along the east bank of the Little Sioux in the west part of section 24 and the southwest quarter of section 13, are a number of exposures of Nebraskan till (Plate XXV). The most southerly of these exposures are in the north part of the southwest quarter of section 24, where the river flows close to the base of the bluff. At several places the Nebraskan till rises ten to twelve feet above the river. At short intervals farther north there are Nebraskan exposures, some of which rise twenty feet above the water. The slopes are badly slumped and Kansan till is in many places mixed with, or slumped down over the Nebraskan till.

In the northwest quarter of section 24, where the river swings farthest to the east, there is a big slide exposure. It is largely slumped over but enough can be seen to make out the general succession. Nebraskan till rises fifty-five feet above the river and is overlain by Kansan till. The exposure is about twenty-five yards across at the Nebraskan-Kansan contact, and at several places this contact was exposed by digging. At most places the tills are in contact, but at one place about four inches of a yellowish silty sand separates them and near the south end of the exposure there is at the contaet a mass of yellow sand and gravel with bowlders, that appears to rest partly in a depression in the Nebraskan till.

About eighty rods north of the southwest corner of section 13, the Nebraskan till outcrops at river level and rises in the bank for about ten feet. Part of the exposure is slumped over with Kansan till from above and a few yards along the bank Kansan till, apparently in place but probably a large slump, comes down to water level. The slope above is slumped and grassed over nearly to the top of the bluff. Other exposures of Nebraskan were seen in a ravine in the southwest part of the northwest quarter of section 13.

Section 1, east of the river, contains a number of Nebraskan drift exposures in the lower part of the bluff of the Little Sioux valley and in tributary valleys (Plate XXV). A Nebraskan till exposure in the slope of the Little Sioux valley about sixty rods south of the center of the section is almost continuous for thirty feet, and rises to fifty feet above the river, and in a ravine valley to the east, exposures appear up to sixty feet above the river. In the south half of the northeast quarter of section 1 the Nebraskan till is exposed in a gully from thirty feet to forty-five feet above the river.

One hundred yards west of the east line of the northeast quarter of section 1, the south slope of a ravine shows the Nebraskan till rising eighteen feet above the ravine bed. This is overlain by two and one-half feet of grayish black material in which were found a few fragments of snail shells. This is probably an Aftonian silt horizon but it is very compact and without laminæ. It is overlain directly by fifteen feet of Kansan till and then the gravel zone rises to the bench level. In the gutter along the road which rises eastward on the north line of section 1, small exposures show the Nebraskan till between thirty feet and forty feet above the river, the black silts with shell fragments at fifty feet and Kansan till between fifty-five feet and seventy-five feet above the river.

The east bluff of the Little Sioux valley about sixty rods north of the south line of section 36, Cedar township, shows a large exposure in which the Nebraskan till extends from the river level fifty-five feet above the water and is overlain directly by the Kansan till. The river is undercutting the bluff at this point and the Nebraskan till is fresh. Near the river level it has a reddish chocolate or dark reddish brown color, but higher up it takes the usual gray color. At the contact, the two tills are much alike and seem to grade into each other, but a few feet on either side of the contact they are distinct and the similarity at the contact apparently is due to a mixing of the two tills. The Nebraskan till breaks into small blocklike pieces and has very few sand grains or pebbles; the Kansan breaks into elongate flakes, is much more gritty, and shows more ferruginous staining along the joints. A few feet above the river at the south end of the exposure there was a lens of greenish gray sand a foot thick and two feet long, and about ten feet above the river was a seam of sandy silt two to three inches thick and about eight feet long. Such inclusions of sandy material in the Nebraskan till are exceptional.

More than sixty exposures of Nebraskan till were seen along Mill creek valley and its immediate tributaries in northern Cherokee county. The locations of many of these are shown in Plate XXV. In the bluff of Mill creek in the southwest quarter of the northwest quarter of section 14, Cherokee township, the first gully east of a large ravine from the north shows Nebraskan till forty-five feet above the creek, and another gully farther east shows Nebraskan till fifteen feet above the creek. The Nebraskan till of these exposures weathers yellow as if it were mixed with Kansan till.

Other exposures of Nebraskan till were seen on the east slope of the large ravine from the north near the west line of section 14; in a ravine near the south line of the southeast quarter of section 15, where it is overlain directly by recent alluvium; in a road-cut north of the house on the H. L. Phipps farm in the north part of section 15; and in the east bank of Mill creek near the quarter-corner on the north of section 15, where it rises forty feet above the creek.

In the west bank of Mill creek sixty to eighty rods north of the south line of section 10, the Nebraskan till rises fifty feet above the creek. At the water level the till has a blue-black color beneath the surface and at a depth of a foot it is exceedingly tough and sticky. Higher up the slope the color is gray at the surface and chocolate-gray beneath. Where it is most weathered it has a yellowish cast. The starchlike fracture is well developed.

In the southeast corner of section 3, Cherokee township, in the valley of a tributary of Mill creek, a steep northward-facing slope shows Nebraskan till rising thirty feet above the creek. The color of the till is gray or yellowish gray at the surface, and chocolate-gray beneath. It has the typical starchlike fracture of the Nebraskan but in this exposure is not very hard. It contains a few pebbles and the matrix is commonly only slightly calcareous. The upper fifteen feet of this horizon contains calcareous concretions as large as two inches in diameter. Fragments of small snail shells were found at several places in this upper part and it is possible that the upper part of the stratum consists of reworked Nebraskan till which forms a compact Aftonian silt. This member is overlain by Kansan till which is only three to four feet thick at the west end of the exposure, thins to less than one foot at the center and apparently is six feet thick at the east end. The whole exposure at this horizon is greatly slumped. Near its base the Kansan till here contains much of the material from below; and yet they are readily distinguishable, and the contact is so definite that hand specimens may be removed containing the two materials. At a short distance above the contact the till is as a rule unquestioned Kansan.

Overlying the Kansan till is a zone, one to three feet thick, consisting of dark greenish or grayish sandy material below, and a black soil-like material above. Both the sands and the soil zone contain shell fragments among which a Unio, a small pelecypod and small snails were recognized. The Kansan till is locally entirely absent and in such places this zone rests on the Nebraskan. Higher up the exposure is very badly slumped. It seems to consist of a twelve to fifteen foot zone of bluish and yellowish sandy silts and silty sands, overlain by twenty to twenty-five feet of the usual valley gravels.

Nebraskan till is exposed along the road that leads down to Mill creek in the southwest corner of section 5, Cherokee township, where it is overlain sharply by the Kansan till (pages 424 to 430), and in the lower course of the ravine that extends northeast across the southeast quarter of section 5, where it rises fifteen feet in the bank (Plate XXV). In the latter exposure it is the weathered phase and has a light grayish blue color at the surface but is dark blue-black below. At the surface it is cracked and loose where it is dry and it looks like a slaked shale exposure, but at a short distance below the surface it is quite hard.

Near the center of the northwest quarter of section 4 Mill creek is undercutting its east bluff and has uncovered a large face of Nebraskan till which extends along the slope for several rods and rises in the bluff to fifty feet above the creek. This is overlain by forty feet of Kansan till. The Nebraskan till of this exposure is a loose chocolate-gray clay. It is unleached, with a few limestone pebbles even at the top of the zone, but at a number of places the matrix is practically free from calcareous material. The till contains many calcareous concretions, some of which are four to six inches in diameter and a few slablike masses were seen which were as much as twelve inches across. Several of these concretions were found to have pebbles at their centers. The concretions appear to be in place even down to twenty to thirty feet below the top of the horizon. A mass of iron-stained, partly cemented gravel four to six feet across was seen enclosed in the Nebraskan till of this exposure. Other exposures of the till appear in the south bank of a creek valley from the west in the east part of section 5, where thirty feet of till is exposed beneath the gravels of the bench area; and in the northeast corner of section 5, where it rises thirty-five feet above the creek and is overlain by a thick layer of gravel.

Farther north up Mill creek valley, in Cedar township, Nebraskan till is exposed in the northwest corner of section 29, where in the east slope of a side ravine from the northeast it is overlain directly by the valley gravels; and near the mouth of the narrow ravine crossed by the road in the south part of section 19, where fifteen feet of Nebraskan till is overlain, up the ravine, by about forty-five feet of Kansan till.

Along the ravine in the north half of the southeast quarter of section 19, Cedar township, there are several exposures of Nebraskan till which rise ten to twelve feet above the stream and are overlain directly by Kansan till. Farther up the ravine, north of the quarter-section line, a grayish black horizon containing a large amount of carbonaceous matter and showing plant impressions and a few decayed stems rises in one exposure three feet, in another five feet, above the ravine bed. It is overlain directly by the Kansan till and its base is not exposed. Where the Kansan and the Nebraskan tills are both present this zone was not observed, but it is probably an old soil and surface accumulation of Aftonian age.

In the north bank of Mill creek in the southwest quarter of the southeast quarter of section 13, Liberty township, Nebraskan till outcrops along the bank for about sixty rods and rises ten to fifteen feet above the water. At several places the Kansan till overlies the Nebraskan with a sharp contact, but in other places a thin gravel layer or pebble zone separates the two tills.

The most northerly exposure of Nebraskan till known along Mill creek is about forty rods south of the north line of section 13, Liberty township. In one part, the Nebraskan till rises fifteen feet above the creek but the contact is uneven and a short distance to the north the Kansan till comes down to water level. The contact is covered by slumped material but at one place where it was exposed by digging the Kansan till rests directly on the Nebraskan.

Aside from the Nebraskan till exposures of central Cherokee county a few others were observed. To the south there is questionable Nebraskan till in the bank of Little Sioux river just east of a gravel pit in the north part of Anthon, in eastcentral Woodbury county. The till rises ten to twelve feet above the river without exposing its upper contact, but a few rods away and at a slightly higher altitude Kansan till appears in the bottom of a pit in the valley gravels. The Nebraskan till of this exposure may be only a great mass included in the Kansan.

North of central Cherokee county along the Little Sioux valley Nebraskan till is exposed in the south bluff in the northwest quarter of section 25, Waterman township, O'Brien county, and in the river bank at Peterson in southwestern Clay county. In the first exposure the Nebraskan is a chocolate-brown clay with very few pebbles and almost no grit and has a well developed starch fracture. It rises eighteen feet above the river level and is overlain directly by the Kansan till. Just east of the east bridge at Peterson the chocolate-brown Nebraskan till rises in the north bank three to four feet above the river, and it appears at river level in the south bank near the east line of section 32. The exposure just east of Peterson is the last Nebraskan outcrop seen in passing up the Little Sioux valley.

A GROOVED AND STRIATED NEBRASKAN-KANSAN CONTACT PLANE.

In the southwest corner of section 5, Cherokee township, a road from the upland descends a small ravine to Mill creek (Plate XXV), and there was shown at the roadside in 1911 and 1913 a good exposure at the Nebraskan-Kansan contact. The contact is essentially horizontal for the length of the exposure, twelve to fifteen yards, and passes in one direction beneath the level of the road, while in the other direction it rises above the road-cut, and is concealed in the grass-covered slope. The contact plane was followed into the bank (east) a few feet, and in that direction also it is approximately horizontal. The Nebraskan till below is tough purplish gray clay, with very few sand grains or pebbles, but with some calcareous nodules. The Kansan till above is bluish black clay when fresh, and weathers to the usual brownish yellow color. It contains considerable grit and many pebbles. The contact plane is very definite, without a transition zone, so that it is possible to remove hand specimens that contain the two very distinct tills. The upper till can be removed so as to leave the surface of the lower till exposed, or a block containing the two tills can be removed and then separated along the contact.

Both surfaces of the contact, the Nebraskan below and the Kansan above, are smoothed to an even plane. These surfaces are marked by parallel grooves and ridges, the larger of which measure a quarter to a half an inch across, and a sixteenth to an eighth of an inch in depth or height. From these they grade down to the very finest of line striations, which cover the entire surface, even the slopes of the larger ridges and grooves. A view of these contact surfaces is shown in figure 60.

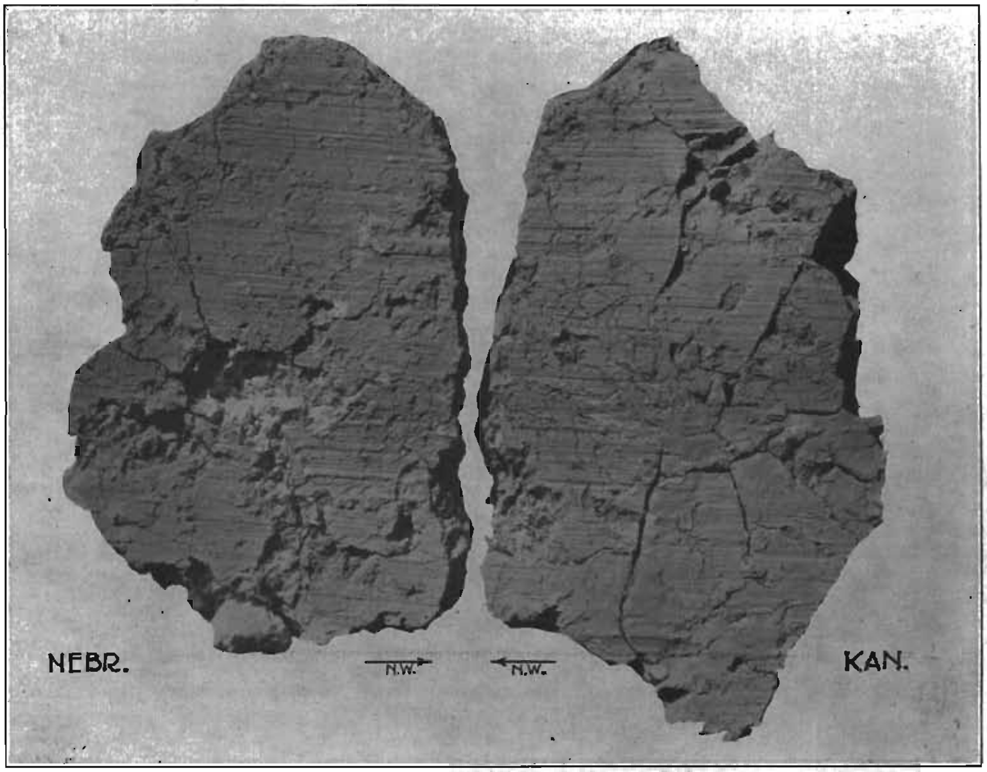


FIG. 60. A grooved and striated contact plane between the Nebraskan and the Kansan tills. A mass of clay containing the Nebraskan-Kansan contact was removed from the bank and later was separated along the contact plane. The Nebraskan is on the left and the Kansan on the right. A close study of the figure will show that one surface is the exact counterpart of the other. For description of features shown see text.

The under surface of the Kansan till above the contact plane is veneered with a thin layer of Nebraskan till so that both sides of the contact really show Nebraskan material. This veneer commonly has a thickness of about an eighth of an inch, but in some places it is lacking altogether and in some places it evens up the lower surface of the Kansan till by being several inches thick. The Nebraskan till contains very few pebbles but small calcareous concretions are rather abundant. These appear on the face both above and below the contact plane, but are much more abundant on the lower side. In either position they may be smoothed and striated. In some cases, a single striation can be traced from the clay across a pebble face and onto the clay again. The direction of the grooves and striæ of this exposure is N. 60° W.—S. 60° E.

The surface on one side of the plane is the exact counterpart of that on the other, the elevations or ridges of the one fitting into the depressions or grooves of the other. Where a pebble projects above the general surface of the Nebraskan, its northwest slope is buried in clay which forms the beginning of a ridge of clay that continues to the northwest (figure 60). The southeast slope has no clay on it and is more worn and striated than the northwest slope. Around the lateral slopes of the pebble, as seen from the southeast, little grooves are in some cases dug out, and striae approaching the lateral parts of the pebble from the southeast swing to the right or left of these grooves, pass around the lateral slopes, and then extend directly on to the northwest, not swinging back behind the pebble. Where a pebble projects from the lower side of the contact plane there is an exact impression of the projecting part of the pebble directly opposite in the surface above the plane, and this impression is the beginning of a groove which continues to the northwest. The groove, terminating to the southeast with an impression of the pebble, fits down over the ridge which terminates with the pebble itself (figure 60). If the profile of the projecting pebble normal to the direction of grooving is uneven, the ridge to the northwest of the pebble and the groove which fits down over this ridge will show a corresponding uneven cross-profile.

A smaller number of pebbles and concretions project from the plane above the contact. These have the northwest slope more worn and striated, while the southeast slope is buried in clay, which forms the beginning of a ridge which continues to the southeast. A pebble of this upper surface projects downward into an impression in the lower surface and this depression is the beginning of a groove that continues to the southeast, and contains the ridge projecting from the upper surface.

The upper side of the contact plane is not the mold of the lower side. This is shown by the following points. (1) The surface facing downward on the contact plane is striated, the same as the surface facing upward. Although grooves and ridges could be molded, it is probably not possible to mold striæ or striæ ridges which are too small to allow clay to fit down over or into them. (2) The pebbles projecting downward from the upper side of the contact plane are striated parallel with the grooves, and to accomplish this they must have been in their present position in contact with the lower till surface over which they were shoved. (3) For each pebble projecting from one surface there is a groove on the other surface, and the shape of this groove shows that it is the path along which the pebble passed. (4) The contact plane, which represents the plane of movement, is below a thin layer of Nebraskan till which veneers the base of the Kansan. This veneer was adhering to the Kansan till when the grooves were made. These lines of evidence prove that the upper surface of clay, the Kansan, was in contact with the lower when the grooves and striæ were made, and that each surface striated the other.

The relation of the features is evident. The smooth contact plane was made by the movement of the Kansan till above the plane, over the surface of the Nebraskan till below the plane. The grooves were made by the projecting pebbles and mark the paths along which the pebbles have passed. The pebbles projecting into the impressions, occupy the very positions in which they were left when movement along the contact plane stopped. The minor grooves and striations also were made by small pebbles or sand grains projecting from the opposite side, and many examples were observed showing striæ terminating directly opposite the sand grains which made them. The ridges are on the lee side of the pebbles, and were protected by the pebbles.

We have, therefore, these facts: A smoothed, grooved and striated contact plane between the Nebraskan and Kansan tills, made by the movement of the Kansan till on the Nebraskan till.

As to the cause of this movement, two hypotheses will be considered. (1) Hill-side slumping, or sliding of the upper till on the lower. (2) The movement of the Kansan ice-sheet as it pushed over the Nebraskan till.

The movement of one rock mass on another when under great pressure produces smoothing of the rock surfaces (slickensides), and striated surfaces are common in mines and have been observed in tough clay that has been blasted. The slope upon which the contact here considered appears, is steep but the contact plane in so far as it could be exposed is essentially horizontal, and the weight was only that furnished by fifteen to twenty feet of overlying till.

An ice-sheet shod with stones will groove and striate a bedrock surface, but the question here is, can it groove and striate a surface of till? If the feature was made by an ice-sheet, it was the base of a drift-shod ice-sheet that did the work, rather than the ice itself, for, as shown above, the Kansan till was resting on the Nebraskan till when the phenomenon was developed.

The slope upon which the exposure appears faces the northwest. If slumping produced this contact the motion must have been from southeast to northwest. On the other hand if glaciation produced the feature the movement probably was in the opposite direction, from northwest to southeast.

Where a pebble projects from the lower surface, the groove on the upper surface extends to the northwest. This means that the portion of the upper surface to the northwest of the projecting pebble has passed over the pebble by a movement from southeast to northwest. In the case of a pebble projecting from the upper or Kansan side of the contact, there is a groove in the lower surface to the southeast, that is in the portion of the lower surface over which the pebble has come. This again indicates a motion from southeast to northwest. Also the pebbles projecting from the lower surface are more worn and striated on the southeast side, while those projecting from the upper surface are more worn on the northwest side. This also shows a motion from southeast to northwest.

The evidence seems very conclusive that the part above the contact plane moved from southeast to northwest (S. 60 E.—

N. 60 W.). This is the direction in which slumping would take place, and a direction in which the Kansan ice-sheet certainly did not move. We therefore interpret this grooved and striated contact plane as the work of hillside creep or sliding of the Kansan till upon the Nebraskan.

This phenomenon was first seen in September, 1911. A hasty study in the field and the study of a few specimens brought in led the writer to think that the direction of movement was from northwest to southeast, and the feature was interpreted as the work of glaciation. A short paper on the subject was read before the Washington meeting of the Geological Society of America in December, 1911. The paper was not printed, but abstracts appeared in Science (Vol. 35, p. 316) and in the Bulletin of the Geological Society of America (Vol. 23, p. 735). A later study in the field showed that a mistake had been made in labeling the orientation of the earlier specimens taken, and that the features showed instead a movement from southeast to northwest. This opportunity is taken to correct the error recorded in the abstracts noted above.

At least two exposures in the ravine in the east half of section 19, Cedar township (page 423), show the smoothed, striated contact plane at the Nebraskan-Kansan contact. The exposures are greatly slumped and masses containing the contact plane have been moved down the slopes at several places. The features which indicate the direction of motion are poorly developed and it was not possible to prove the direction of motion. In the second exposure south of the quarter-section line, in the east bank, the direction of striation is N. 40° W.—S. 40° E. The bank is normal to this direction and faces the northwest. The evidence is slightly in favor of movement in a northwest direction. In an exposure in the west bank, sixty to eighty rods south of the quarter-section line, the direction of striation is N. 70° E.—S. 70° W. The bank here is normal to this direction, and slumping would require movement in the direction N. 70° E., which is apparently the direction indicated. These two exposures are only forty to sixty rods apart, but the difference between the direction of grooving is 110°. If glaciation had produced these contact planes the direction of grooving would be approximately the same. The direction of grooving is in both cases normal to the face of the bank and the conclusion is that slumping or creep produced the contact planes.

CHAPTER VII

THE GEOLOGIC HISTORY OF NORTHWESTERN IOWA.

The Pleistocene deposits of northwestern Iowa have now been treated in considerable detail. Practically nothing has been said, however, concerning the bedrock of the region; first, because this is primarily a report on the Pleistocene deposits; and second, because there was very little opportunity for collecting new data on the bedrock formations, which, over most of the areas, are deeply buried by the Pleistocene deposits. In this chapter there will be brought together, chiefly from the literature, some data concerning the bedrock of northwestern Iowa, and then the geologic history of the region will be traced in so far as this is recorded by the bedrock and the glacial deposits.

The Bedrock of Northwestern Iowa.

Within our region the bedrock outcrops chiefly in the slopes of the Big Sioux and the Missouri valleys along the west boundary of the state. Along the west line of Plymouth and northern Woodbury counties, there are many small outcrops, along the west line of southern Sioux county there are a few, and in Lyon county there are two or three outcrops in the very northwest corner of the state. Away from these valleys only two small exposures of bedrock have been reported within the region. The areal extent of all these outcrops is negligible for they are small and most of them are in steep valley-slopes. Ten of the sixteen counties comprising the region here considered are without a single known outcrop of the bedrock.

Two widely separated divisions of the geologic column are represented by the bedrock of the Big Sioux valley, for the few outcrops in northwestern Lyon county are of Proterozoic rocks while those of the counties to the south are of Cretaceous rocks.

The table given herewith shows the principal divisions of the geologic time scale, those divisions which are represented by deposits in northwestern Iowa being printed in italics.

ERA	PERIOD	EPOCH
Cenozoic	*Pleistocene* Tertiary	*Wisconsin* Peorian Iowan Sangamon Illinoian *Yarmouth* *Kansan* *Aftonian* *Nebraskan*
Mesozoic	*Cretaceous* (*Upper Cretaceous*) Comanchean (Lower Cretaceous) Jurassic Triassic	Laramie Montana *Colorado* { Niobrara *Colorado* { *Benton* { Carlile, *Greenhorn*, *Graneros*
Paleozoic	Permian Pennsylvanian (Upper Carboniferous) Mississippian (Lower Carboniferous) Devonian Silurian Ordovician Cambrian	
Proterozoic	Keweenawan *Huronian*	*Sioux Quartzite*
Archeozoic		

THE PROTEROZOIC—SIOUX QUARTZITE.

In the northwest corner of Lyon county there are two exposures of the Sioux quartzite. One of these is in the extreme northwest section of the state within the valley of Big Sioux river, where the rock stands as a ridge twenty feet high and about a quarter of a mile long. The other exposure is two miles east in a small valley in the north part of section 7, Sioux township. These two exposures in Iowa lie on the south border of a large area of quartzite which extends north to Flandreau, South Dakota, a distance of forty-five miles, and has its eastern limit at Redstone Ridge, Cottonwood county, Minnesota, and its western limit at Mitchell, South Dakota. The rock is well exposed at Rowena, South Dakota, just north of the exposures on the Iowa side, in the quarries at East Sioux Falls, in and around Sioux Falls, and at many other places in southwestern Minnesota and eastern South Dakota.

FIG. 61. An exposure of Sioux quartzite at Jasper pool, near the northwest corner of Lyon county. The view shows the stratification of the quartzite, which here dips northward.

The Sioux quartzite is a very hard pink to red vitreous rock. It consists of rounded quartz sand grains, so firmly cemented with silica that the whole resembles a mass of quartz. It is stratified in layers from a few inches to a few feet thick (figure 61), and at some places shows lamination and cross-bedding and ripple-marked bedding planes.

The area within which the Sioux quartzite directly underlies the drift in northwestern Iowa can not be very definitely outlined. Thirty miles east of the exposures in the northwest corner of Iowa, at Ellsworth, Minnesota, 100 feet of Cretaceous rocks intervene between the drift and the quartzite, and twenty-five miles south, at Hudson, South Dakota, there is at least 150 feet of Cretaceous rocks beneath the drift. The actual extent within which the quartzite directly underlies the drift is probably well within these limiting points, and probably amounts to no more than a township in northwestern Lyon county.

The Sioux quartzite and other ancient rocks of Proterozoic and Archean age, form a basal foundation for northwestern Iowa. The upper surface of these old rocks dips southward from its outcrop at an altitude of more than 1400 feet above sea level in the northwest corner of Lyon county, and as shown by well borings, is 878 feet above sea level at Hull in Sioux county, 215 feet above sea level at LeMars, and 135 feet below sea level at Sioux City (figure 62).

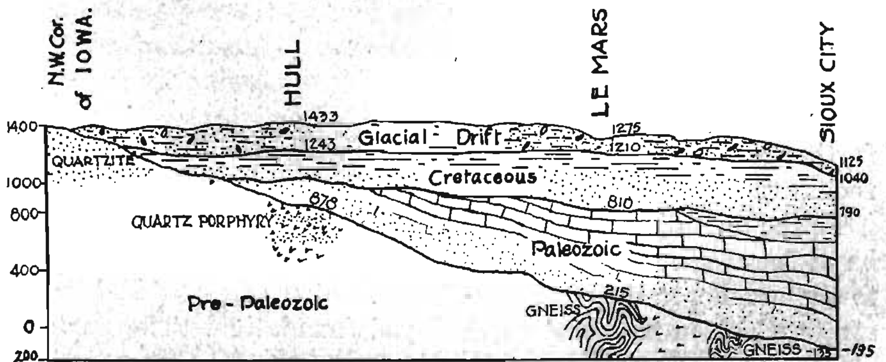


FIG. 62. A geologic section from the northwest corner of the state southward to Sioux City.

THE CRETACEOUS.

Northwestern Iowa lies just within the eastern margin of the great area of Cretaceous rocks of the Great Plains, and the chief bedrock formations belong to the Cretaceous system. The divisions represented are the Dakota formation and the three members of the Benton formation (see table, page 431).

Outcrops appear at intervals in the slopes of the Big Sioux valley south from the mouth of Rock river and in the bluffs of the Missouri valley south to Sargent Bluff, six miles south of Sioux City. Away from the large valleys on the west, as noted above, only two bedrock outcrops have been reported within the region, and these are both of Cretaceous age. One of these, reported by Bain,[60] is two miles northeast of LeMars, Plymouth county, in the west bank of Deep creek, in the west half of the southwest quarter of section 2, and shows four feet of blue-black clay shale belonging to the Graneros member of the Benton formation, overlain by twelve feet of thin-bedded limestone and chalky layers of the Greenhorn member.[61] The other exposure, reported by Macbride,[62] is in the southeast corner of Sac county. It is really a number of small exposures in the slopes of Raccoon river valley extending about a mile in either direction from Grant City. The Dakota and the two lower members of the Benton are shown.

There is abundant evidence that the Cretaceous rocks underlie the drift of practically the whole of the area, for they are the first bedrock penetrated by every deep well that is known within the region. Ten to fifteen miles east of the region the east edge of the Cretaceous area is reached. Mississippian and Pennsylvanian rocks lie to the east. Mississippian limestone is exposed at Gilmore on the east line of Pocahontas county, and farther east along the Des Moines river valley the Pennsylvanian rocks are exposed.

To the north in Lyon county the Cretaceous rocks rest on the basal foundation of pre-Paleozoic rocks, but over all the region to the southeast they rest on the truncated edges of Paleozoic strata which in turn rest on the basal foundation. The records of several deep wells are shown in figure 63 and the structure of the bedrock in a north-south direction is shown in figure 62.

Geologic History of Northwestern Iowa.

PRE-PLEISTOCENE.

Proterozoic.—The earliest recorded event in the history of northwestern Iowa is the deposition of the sand from which the Sioux quartzite was formed. Long continued weathering with mature decomposition had affected the region from which the sand was derived, for nothing remains that might be decomposed with longer time. The sand was well worn in transit

[60] Iowa. Geol. Survey, Vol. VIII, p. 332.
[61] Bain interpreted this section as Niobrara over Benton, but the divisions then considered Pierre, Niobrara and Benton were later shown to be the three members of the Benton.
[62] Iowa Geol. Survey, Vol. XIII, pp. 525-531.

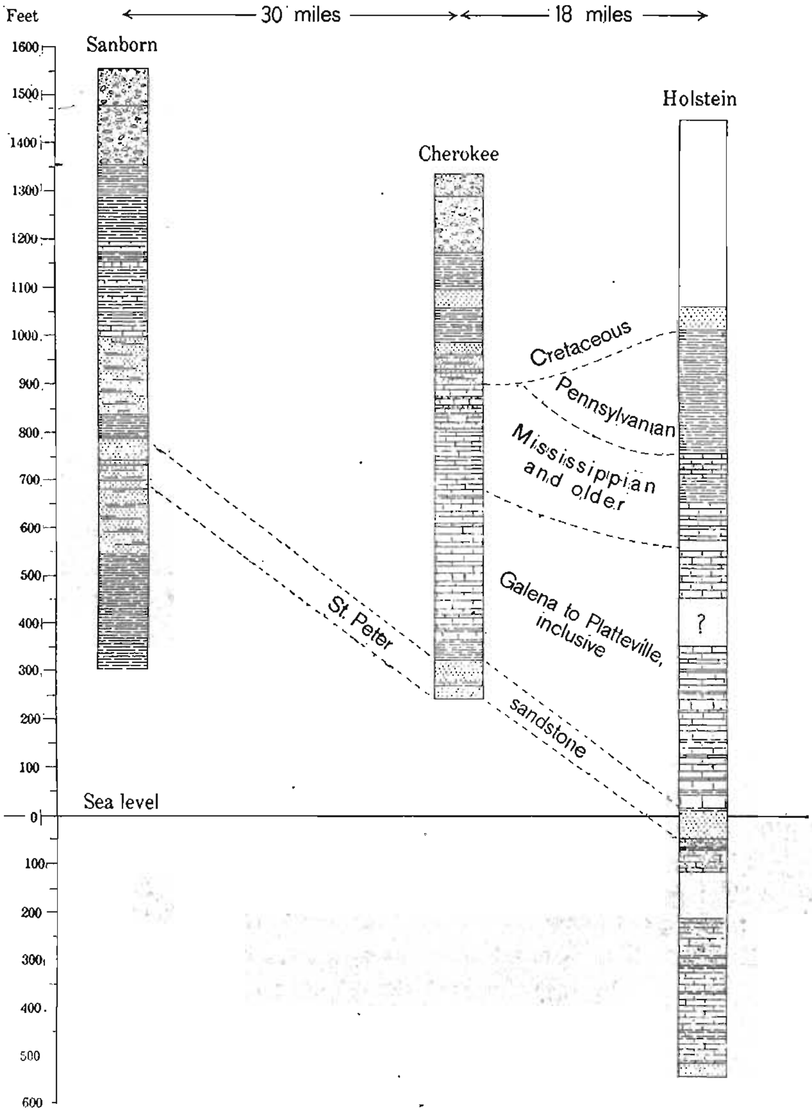


FIG. 63. Columnar sections of deep wells at Sanborn, Cherokee and Holstein. (Norton, Iowa Geological Survey, volume XXI, page 1006.)

and well sorted before or during deposition. The waters were shallow, and at many places the sand was deposited in cross-bedded layers and the shallow bottoms were rippled by the motion of the water. At times, sand deposition gave place to silt deposition, and at other times to gravel deposition. These deposits were later consolidated to sandstone, shale and conglomerate, and finally to quartzite, slate and quartzite conglomerate.

Some time after the formation of the Proterozoic rocks igneous material was intruded into them and this forms the igneous horizons penetrated by the deep well at Hull, as well as the igneous rocks exposed in the valley of Split Rock creek at Corson, South Dakota, and in the Big Sioux valley northeast of Sioux Falls. This intrusion took place deep beneath the surface under high temperature and pressure, and cooling was sufficiently slow to allow the formation of a coarse, wholly crystalline rock. Subsequent erosion has brought the surface down to the horizon of these deep seated intrusions.

Paleozoic.—The Paleozoic history of northwestern Iowa is only partly known. Deposition took place over most of the region during late Cambrian and Ordovician times (figure 63), and again during the Mississippian period, but in Middle Paleozoic time the region was probably land. These early and late Paleozoic seas extended northwestward as far as southern and eastern Lyon county and may have entirely covered the quartzite area (Sioux island). The sediments deposited included all the usual materials, sand, mud and calcareous ooze, and the common sedimentary rocks resulted from their cementation.

Mesozoic.—Following the late Paleozoic deposition the region again became land and remained so through the early part of the Mesozoic era, but in the Cretaceous period the great plains area of deposition spread eastward until it included the western half of Iowa. During the Dakota epoch the deposits were sand and mud, deposited on plains or in marshy areas. Then followed the Colorado epoch, when the areas of deposition were more distinctly marine. It began with the deposition of about fifty feet of mud which now forms the Graneros shale member at the base of the Benton. The seas then gradually became clearer, and the muds were mixed with, or even gave place to calcareous oozes, the whole accumulating in sufficient thickness to form the thirty foot Greenhorn limestone member of the Benton. During this stage abundant marine life existed and left its remains in the limestone. Mud deposition again succeeded and the material that now forms the Carlile shale was deposited. No rocks of the Niobrara formation, the upper part of the Colorado series, are known within the region, but they exist fifteen or twenty miles to the west. Deposition in northwestern Iowa probably ceased with the Colorado epoch, at the close of which there was a general restriction of the Cretaceous seas of the Great Plains. The Cretaceous deposits covered at least part of the Sioux island and may have completely buried it.

The erosion which followed the withdrawal of the Cretaceous seas probably continued uninterruptedly, except locally, to the Pleistocene. It exposed the Sioux island, wore back the edges of the Cretaceous deposits and removed the upper part of these rocks from all of the region. The pre-Pleistocene topography of northwestern Iowa probably had considerable relief and was probably in the mature stage of the erosion cycle.

PLEISTOCENE.

Nebraskan.—After the long interval of erosion from the Cretaceous to the Pleistocene, a change of climate took place and there alternated in the northern part of North America, times when great ice-sheets developed and spread southward into the upper Mississippi basin, and times when the ice disappeared entirely from this region. The first of these ice-sheets was the Nebraskan, the oldest ice-sheet known in the Mississippi basin. It covered the whole of western Iowa and pushed southward into Missouri.

The Nebraskan ice-sheet gathered material from all the formations over which it passed, igneous, metamorphic and sedimentary, but the most important source of the material which was left in northwestern Iowa, was the shales of Cretaceous age which covered eastern North and South Dakota, western Minnesota and western Iowa. This source explains the very compact, somewhat calcareous clay, almost free from grit and pebbles, which characterizes the Nebraskan till. The thickness of the drift deposited was probably 100 to 200 feet in many places.

After the Nebraskan glacial epoch the ice disappeared entirely from this region and the Aftonian interglacial epoch followed. Evidence exists in southern Iowa and as far north as

Crawford and Carroll counties to prove that the Nebraskan till surface remained for a long time undissected and that there was developed on it, chiefly by chemical weathering, a zone of gumbotil (page 416). It is probable that the same conditions existed and that the same gumbotil zone was developed over northwestern Iowa. Stream erosion then dissected the Nebraskan drift plain. During this time some large gravel deposits (Aftonian) accumulated along many of the larger valleys farther south in western Iowa, but within our region there appears to have been little gravel deposition at this time. Along the Little Sioux valley through Cherokee county where a number of exposures show the Nebraskan-Kansan contact, Aftonian gravels are not present.

Kansan.—After a long period of deglaciation, climatic conditions changed again to those favorable for glaciation, and the Kansan ice-sheet developed. This was the greatest of the ice-sheets which invaded the Mississippi basin. It covered most of Minnesota and Iowa, eastern North and South Dakota, and eastern Nebraska, and spread southward over northern Missouri and northeastern Kansas. Northwestern Iowa was 300 to 350 miles inside the southern margin of this ice-sheet at the time of its maximum extent, but only 50 to 100 miles east of the west margin. The thickness of the ice in this region was great and increased to the north and east. If the average distance which the ice traveled after crossing our region be taken as one hundred miles, and if an average gradient of fifty feet per mile be assumed for the first twenty-five miles back from the edge, and ten feet per mile for the remaining seventy-five miles, a thickness of two thousand feet is obtained. As the distance and gradients assumed above are conservative, we may safely assume that our region was buried beneath ice which probably was something like half a mile thick.

Little is known concerning the pre-Kansan topography of northwestern Iowa, but it probably was mature and of moderate relief. The chief surface formation was the Nebraskan till, although in the larger valleys, Aftonian gravels may have existed and locally the bedrock probably was exposed. Large quantities of Nebraskan till were plowed up by the Kansan ice-sheet and mixed thoroughly with the material already carried, becoming thereby part of the Kansan till. Some smaller masses of Nebraskan till were inclosed, without mixing, in the Kansan till. At some places the surface of the Nebraskan till was plowed up, but the material was only partly mixed with the Kansan till and so formed a transition zone from one to the other.

As the Kansan ice sheet advanced, great floods of water loaded with debris flowed out from its front and at a short distance from the ice-front began to drop their load of gravel and sand. With farther advance of the ice-front some of these deposits were plowed up and the sand grains and pebbles were mixed with the materials carried by the ice, making a more pebbly till. Some of the masses of the gravel, firmly frozen when plowed up, were incorporated as gravel bowlders in the till (pages 357 to 361). Any gravel deposit which existed in the region overridden by the ice might have been plowed up in this way whether it was outwash from the advancing ice or Aftonian or other gravels.

During the general stage of ice advance there were temporary withdrawals, and during the general stage of retreat there were temporary advances. As a result of these oscillations of the ice-front, gravel that was laid down just beyond the ice-front was later overridden and buried under till. In some places the oscillations were repeated several times and resulted in several alternations of the till and gravel as described for the Mill creek bluffs north of Cherokee (pages 372 to 376).

For the history of the time following the withdrawal of the Kansan ice-sheet we are again dependent upon the region farther south in Iowa. Over southern Iowa, as far north as Crawford and Carroll counties, the even drift-plain left by the Kansan ice-sheet remained for a long time undissected and on this plain there was developed a gumbotil zone (page 332). It is believed that a similar gumbotil zone was developed also over northwestern Iowa (pages 332 to 334). The development of these Nebraskan and Kansan gumbotils must have required a very long time and our conceptions of the Aftonian and Yarmouth intervals must be lengthened to make allowance for them.

Following the development of the gumbotil, the Kansan drift-region was elevated and erosion began. In southern Iowa this erosion has lowered most of the country below the gumbotil plain, but has left a few remnants. In northwestern Iowa erosion is believed to have reduced all the country below the level of the original plain and to have removed every remnant of the gumbotil (page 332). This erosion also removed the leached zone of Kansan till which was developed below the gumbotil. In this way the absence of a leached zone of Kansan till in northwestern Iowa is explained (page 338).

As the surface was lowered by erosion the gravel masses inclosed in the Kansan till were exposed. Because of the greater porosity of the gravel, these masses are more resistant to erosion than the inclosing till and they have come to be low gravel hills or mounds (page 362 to 372).

After this erosion had progressed well toward its present stage, gravel accumulated in most of the valleys of the region, forming the deposits which have been described above as valley gravels. The material for these gravels is believed to have been released by the erosion of the Kansan till (pages 411 to 414).

After the deposition of the valley gravels and probably soon thereafter, the entire Kansan drift-region was covered with a mantle of loess, the material for which was derived chiefly from the valley flats on the west line of the state. The thickness of the loess decreases eastward from twenty to thirty feet near the Missouri river to two to four feet in the eastern part of the Kansan area. Within the valleys the deposit formed on the valley gravels was not the true loess but a loesslike clay that is the time equivalent of the loess.

The interval of time from the Kansan to the next ice invasion of northwestern Iowa (Wisconsin) includes the Yarmouth, Sangamon and Peorian interglacial and the Illinoian and Iowan glacial stages. The Kansan gumbotil probably was formed chiefly during the Yarmouth stage. The dissection of the region and the accumulation of the valley gravels was completed by Iowan time if the loess is of Iowan age (page 357). Since the loess was deposited it has been leached to a depth of four to six feet and has been removed or re-worked on many of the steeper slopes.

Wisconsin.—During the Wisconsin ice-epoch a lobe of ice seventy to eighty miles wide pushed down across northcentral Iowa, two-thirds of the distance across the state. The west edge of this lobe lay across the eastern part of our region (pages 256 to 292 and Plate XV). This boundary makes several abrupt changes of direction, as east of Dickens and east of Milford, which are believed to be at the angles where minor lobes joined or overlapped each other. The exact history of these lobes, which were either contemporaneous or followed each other closely, will be known only after a thorough study of the Des Moines lobe not only in Iowa but also in southern Minnesota.

In Minnesota the west margin of the ice pushed up to the crest of the Coteau des Prairies, the high divide between the Mississippi and Missouri drainage basins, and the drainage from the ice-margin flowed southwestward to Big Sioux river. The drainage from forty-five miles of this front flowed away by Rock river and its tributaries across Lyon county.

South of central Osceola county the ice-edge did not reach the great watershed, and the southeastward flowing streams were dammed by the ice-margin, and diverted to more westerly courses. The most important diversion was that of the Ocheyedan-Little Sioux system (pages 310 to 318), the waters of which were diverted farther and farther westward until they finally crossed the great watershed in the southwest corner of Clay county, and entered a valley extending southwestward to Missouri river. Since this course across the watershed carried the drainage from about a hundred miles of the ice-margin, and from about eight hundred square miles between the great watershed and the ice-margin, the erosion along it was rapid and the course across the divide was soon firmly established. There was also a rapid deepening of the valley, the present Little Sioux, which carried the waters southwestward, and these valleys were soon worn to approximately their present depths. As the ice withdrew from its maximum extent, other courses were opened up southward on the east of the great watershed, and the quantity of water carried by the Little Sioux was decreased. It was possibly at this time that erosion was replaced by deposition and the gravels within the narrows of the Little Sioux valley were deposited. After the final disappearance of the ice, the streams again became eroding streams, and have cut their present channels in the valley-filling or have locally removed it entirely from their valleys.

The Wisconsin ice-sheet left a drift surface that is characteristically glacial, with strong morainic topography locally. Very little modification of this topography has been produced by the erosion of post-Wisconsin time except along some of the larger streams, which have cut prominent trenchlike valleys (pages 327 to 330).

CHAPTER VIII

SUMMARY AND CONCLUSIONS.

The conclusions reached concerning the various subjects that have been treated in this report, generally have been stated in connection with the discussions of these subjects, but it may be serviceable to bring together here a brief summary of them. The reader is referred to the respective chapters for the fuller statement and the evidence.

Wisconsin Boundary.—The course of the Wisconsin boundary is traced in Chapter II (pages 255 to 293), and shown on Plate XV. This boundary is essentially as traced by Professor Macbride across Sac and Buena Vista counties, the changes made being of minor importance and due to more detailed work. The boundary was shifted two miles farther west just south of the Wall lake outlet in Sac county, was placed a little nearer Brooke creek in northwestern Buena Vista county, and was extended farther up into the angle formed by Brooke creek and Little Sioux river valleys. The boundary from the south line of Clay county northeast to Dickens is approximately as mapped by Professor Macbride in his section on "The Margin of the Wisconsin Drift" in the report on Cherokee and Buena Vista counties (figure 28, page 249).[63]

[63]Iowa Geol. Survey, Vol. XII, pp. 325-338, 1902.

This course, however, was not mapped as the boundary on the Clay county map or discussed in that report.[64] From Dickens northwest to the state line, the writer found the course of the boundary quite different from that shown by Professor Macbride either in the reports on Clay, Dickinson and Osceola counties, or in the section on "The Margin of the Wisconsin Drift" in the report on Cherokee and Buena Vista counties. This portion of the boundary has been discussed on pages 270 to 287.

The separation of the Wisconsin and pre-Wisconsin drift-plains of northwestern Iowa is based chiefly on physiographic grounds. South of our region where the Kansan drift is maturely eroded and well weathered, the separation is distinct; where strong morainic features appear along the Wisconsin border, the separation also is distinct; but where the region to the west is not eroded, and the margin of the Wisconsin drift is not morainic, the separation is a matter of difficulty. The data furnished by the drift and by the loess-covering accord with the physiographic separation. There is little outwash from the Wisconsin drift except along a few large valleys.

The so-called Altamont moraine of Wilder in western Lyon county is not a moraine, but part of the area so mapped is the eroded edge of the upland and part is on the terrace, which is here covered with Indian mounds (page 296). The Altamont moraine mapped by Wilder in northeastern Lyon county is not Wisconsin drift (page 363).

Kansan Drift.—All of northwestern Iowa west of the Wisconsin drift-boundary is assigned to the Kansan drift-region on the basis of the identity of the till and of the presence of a mantle of loess over the entire region. The absence of leached Kansan till in northwestern Iowa is explained by the removal of this leached zone by erosion of the entire region below the original level at which leached till may have formed.

The Loess.—The entire region west of the Wisconsin drift-boundary is covered with loess. In the southwest part of the region this is typical loess and is thick. To the northeast it thins to a mantle of only two to three feet and lithologically may

[64]Iowa Geol. Survey, Vol. XI, pp. 461-508, 1901.

not be typical loess, but it is the time equivalent of the loess. An equivalent loesslike clay overlies the valley gravels.

Nebraskan Drift.—The dark colored compact till which is exposed beneath the Kansan at many places along the Little Sioux valley in Cherokee county is Nebraskan till. There is, however, no development of Aftonian gravels, and only a few areas of Aftonian silt were recognized. The Nebraskan till probably underlies the Kansan till quite generally in northwestern Iowa, probably at many places forming the major part of the great thickness of Pleistocene deposits.

Drainage Changes.—The great watershed of northwestern Iowa in pre-Wisconsin time extended from the middle of the south line of Sac county, northwest across the Boyer valley and then followed the divide to the west of the Boyer valley instead of the one to the east as at present. The upper course of the Boyer then drained east to Raccoon river by way of the Wall lake outlet (pages 318 to 320).

Farther north, in western Buena Vista county, this watershed crossed the Little Sioux valley either to the divide west of Waterman creek or to the divide east of that stream and north of the Waterman creek basin it continued along the high divide of northcentral O'Brien and central Osceola counties, and northward along the Coteau des Prairies. The Ocheyedan-Little Sioux system above Spencer at this time continued east past Dickens to Des Moines river and the streams of western Clay county, and possibly Waterman creek continued southeast into the present Wisconsin drift by courses now obliterated (pages 313 to 318). The changes which brought about the present system occurred most probably in the Wisconsin ice-epoch, when the eastward and southeastward flowing streams to the east of the great watershed were obstructed by the Wisconsin ice, which spread westward nearly to the crest of the divide in western Buena Vista county, and which lay across the east end of the Wall lake outlet in southern Sac county.

Interbedding of Gravel and Till—An interbedding of gravel and till characterizes the Kansan drift of several exposures (pages 372 to 380). These deposits were formed by oscillations of the ice-front during the general stages of advance and retreat.

By these oscillations, gravel deposited just beyond the ice-edge may have been laid down on till only recently deposited and may soon have been buried by till. The freshness of the gravel and till of these layers shows that neither was exposed long at the surface before the next higher member was deposited.

Gravel Bowlders and Gravel Hills.—The gravel and sand masses included in the till (pages 357 to 361) are parts of frozen gravel deposits which were plowed up by the advancing ice-sheet. As is shown by the composition of the gravel, by the freshness of the material and by the clay-balls, most of these masses are of the same age as the inclosing till. They represent deposits made in front of the advancing ice-sheet, which a little later plowed them up (page 361.)

The gravel hills of the Kansan drift-region are included gravel bowlders which have been exposed at the surface by the removal of the inclosing till. They come to stand above the surface of the till by the relatively greater resistance to erosion of the porous gravel mass.

The Valley Gravels.—The valley gravels occupy valleys cut into the Kansan drift. The material for these deposits was released by erosion from the Kansan drift and was accumulated in the valleys during a period of time subsequent to the major erosion of the Kansan drift-plain and preceding the deposition of the loess.